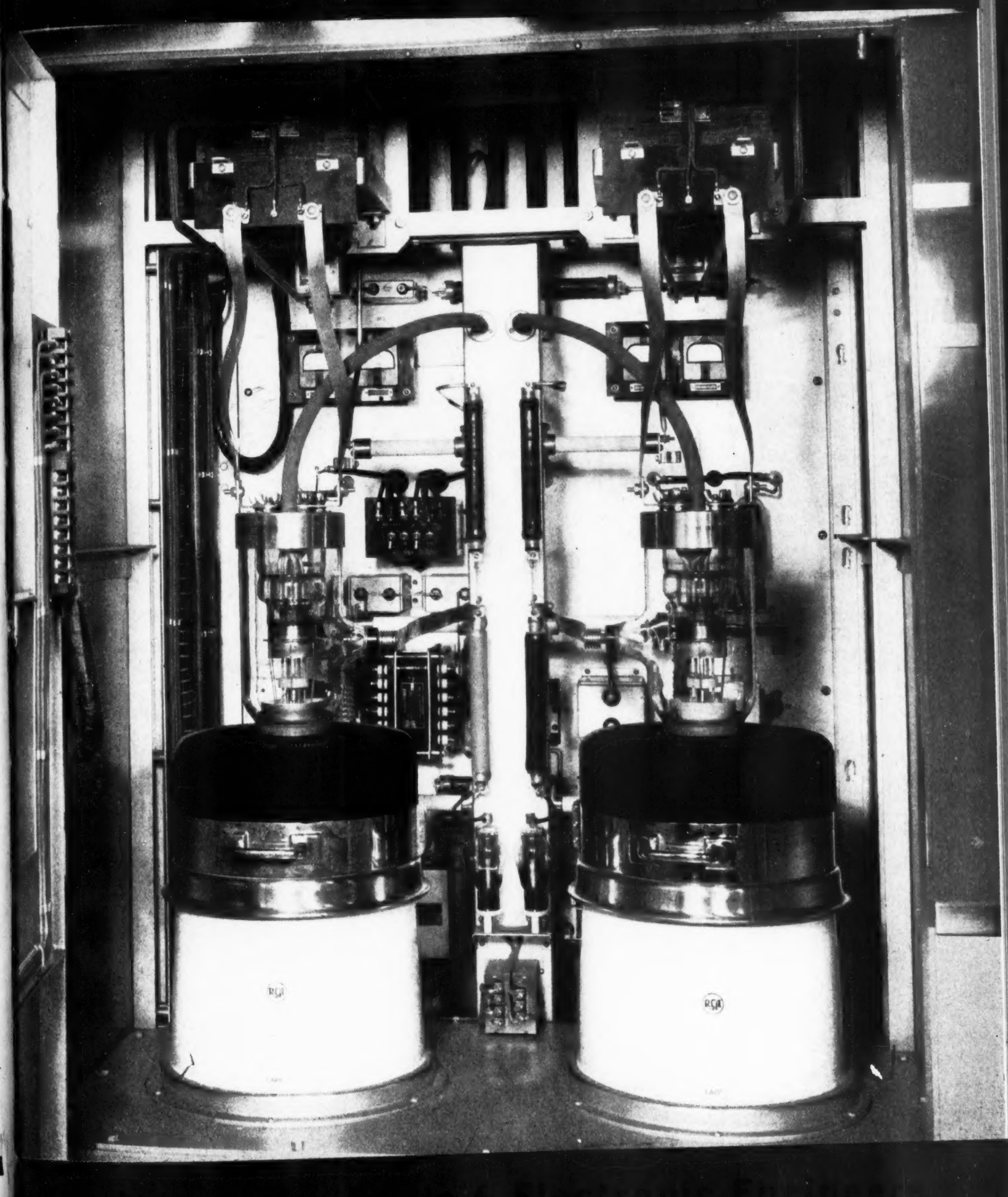
RADIO

Operation



& Electronic Engineers


wherever a tube is used...
Series 175 Relay

RADIO

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AUGUST 1944 Vol. 28, No. 8

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COVER

Oscillator unit of 50-kw transmitter at Station WCAU. (*Courtesy of RCA Manufacturing Co., Inc.*)

ARTICLES

MISCELLANEOUS

RADIO Magazine (title registered U. S. Pat. Off.) is published monthly at 34 N. Crystal Street, East Stroudsburg, Pa., by Radio Magazines, Inc. Executive and Editorial Offices at 342 Madison Avenue, New York 17, N. Y. Subscription rates—United States and Possessions, $3.00 for 1 year, $5.00 for 2 years; elsewhere $4.00 per year. Single copies 35c. Printed in U.S.A. Entered as Second Class Matter October 31, 1942, at the Post Office at East Stroudsburg, Pa., under the Act of March 3, 1879.

Transients

MASS PRODUCTION

★ The problem of producing large quantities of radio receivers at a profit in a highly competitive market is one which deserves a great deal more thought than has been given to it. We are not thinking, of course, of the period immediately following reconversion and the resumption of civilian radio production. During this period the demand for new radios should outstrip production facilities even though, as seems probable, the unit price will probably be higher than pre-war models.

But it is unlikely that the demand will exceed the supply for more than a year or so. And, during reconversion, millions who enjoyed war-inflated incomes and a degree of economic security are going to find their incomes reduced or their jobs gone. Faced with the need for economy, it is probable that they will not spend as much for new radios as surveys taken at the present time may indicate.

While this condition will unquestionably make it easier for manufacturers to build more efficient organizations and thus reduce costs, it is likewise apparent that this advantage will be available to all employers. Therefore, in the face of lowered national income, far greater competition for the consumer's radio dollars, and a buyer's market, there will be a greater need than ever before for newer and better methods in the mass production of receivers.

In general, there has been little progress made in finding improved methods of producing receivers in quantity. To be specific, twenty years ago a visitor to a radio factory would find hundreds of women sitting at assembly benches or belt conveyors, wielding soldering irons. Now, similar hands, perhaps more often Luxified, perform the same soldering operations. Soldered connections has become such an accepted method of wiring radios that a great many production men estimate labor costs of new designs on the basis of the number of soldered joints in the apparatus to be built.

But why solder? When we stop to consider the large number of mechanical joints which are not soldered—such as tube pin contacts—in receivers as presently produced the possibility of finding some simpler, satisfactory, more economical and faster method of production does not seem too remote. Welding, for example, has been tried. And it works. So likewise have solderless connections, formed by crimping tools. While we don't think soldering should be completely eliminated—there are servicing problems involved, too—surely this traditional method deserves more thorough scrutiny.

And why so much wiring? Elaborate and costly wiring harnesses are carry-overs from the telephone communications industry, whence so many radio engineers have come. In small receivers, at least, it might be well worth while to investigate other methods of mass production which offer promise of reducing costs.

Not that other methods haven't been tried. They have; but often too soon, when there was no great need for radical changes in production methods. Nor have some of the alternative methods been given thorough study and a fair trial. One method, for example, employed a plastic chassis with formed grooves into which molten copper was poured, reaching points to be interconnected. Another method utilized copper strips with riveted joints. Still another was to make mechanical joints to projecting tabs on components, the chassis being subsequently suspended in molten solder so that all joints were simultaneously soldered.

There are objections to all the above schemes, some of which are patented. But this does not mean there is no way out. One company is now producing coils by electroplating glass forms, with terminals molded in place. Another proposed assembly method, adaptable to small receivers, is to interconnect mechanically the various components and then seal the chassis by molding in plastic. There would be no servicing problem; the unit cost could be kept so low that the chassis as a whole could be economically replaced in the event of breakdown of some component.

Less spectacular, but available to all manufacturers as a tried and proven method of reducing costs in mass production, is standardization. It is becoming more and more apparent that there is far too great a variety of component sizes, values and styles called for on design specifications. This is especially true in large organizations where many engineers work independently on projects. Many such concerns have found it profitable to set up a separate department solely for standardization. This department makes tests, selects suppliers, establishes mechanical and electrical tolerances in cooperation with component manufacturers, and gathers specific information regarding the performance characteristics of components. Results are less waste, smaller inventories, and better products.

Smaller manufacturers can avail themselves of the American War Standards, which are a vital contribution to mass production efficiency. But these standards, being general, need to be supplemented with data individually gathered covering factors directly applicable to the manufacturer's products and production methods.

MOURNING BECOMES ELECTRONICS

★ Has electronic heating been used in crematories?

—*J.H.P.*

TECHNICANA

HIGH FIDELITY REPRODUCTION

★ High fidelity reproduction is not all that has been claimed for it, according to H. A. Hartley in an article entitled "Aesthetics of Sound Reproduction" appearing in the July, 1944 issue of *Wireless World.*

The great objection to present high fidelity reproduction, according to the author, is that with a wide frequency response and a trained ear, distortion of the higher harmonics becomes appreciable, particularly when scratch and interference have been eliminated, making the distortion more noticeable.

Mr. Hartley finds that "judicious distortion" in the response produces a result more enjoyable to the artistic ear. Some of the things to be avoided in "doctoring up" the response are cabinet resonances, air column resonances in the cabinet, resonances in the speaker and pick-up, tube overload, and bass and treble attenuation. The 3000-cycle resonance in a poor speaker, for example, must be eliminated.

Scratch is not to be eliminated by cutting off the top frequencies but by maintaining an overall flat response up to 10,000 cycles or more. Scratch can extend over a range of 2000 to 8000 cycles, or more.

The "doctoring" is effected by introducing depression in the response curve, wherever most effective. It is claimed that the ear is less sensitive to depressions than to peaks in the response, but that the effect of eliminating noises created on the surface of a record is very great when the response depression can be made to coincide with the unwanted frequency.

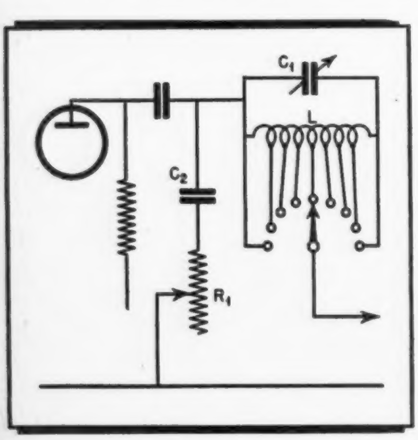

Figure 1

The sharp dip is injected by use of a rejector circuit such as is shown in *Fig. 1.* The tuned circuit LC_1 must have low losses. This is possible if C_1 is an air trimmer of about 50$\mu\mu f$ and L is approximately 3 henries, air cored, using wire no smaller than #36 gage.

By adjustment of the tapped coil, and C_1, the point of maximum attenuation can be adjusted within the range of 4,000 to 10,000 cycles. Dips of more than 40 db are possible, over a fairly narrow band.

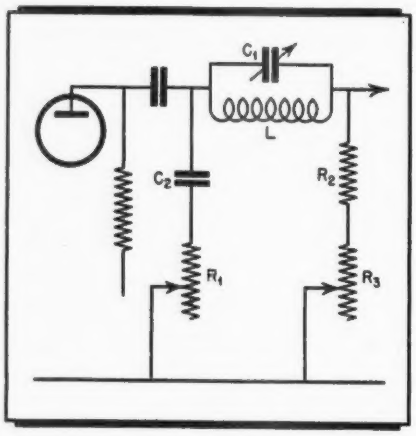

Figure 2

The author recommends the use of a tapped coil so that records to be reproduced can be marked in advance to show the ideal tap number.

For old and worn-out records, top-frequency cut-off is recommended, as shown in *Fig. 2.*

C_2 should be .02 μfd and R^1 100,000 ohms. With R^1 at minimum setting the top-frequency attenuation is high.

Two rejector circuits in series are suggested for further experimentation.

The article is to be concluded in a later issue.

LINEAR SWEEP CIRCUITS

★ When the ordinary gas triode is employed in a cathode-ray tube sweep circuit the output is not a perfect saw-tooth wave. The voltage rise is not strictly linear, but exponential in shape, and the voltage drop is not instantaneous. The tube trace is consequently distorted.

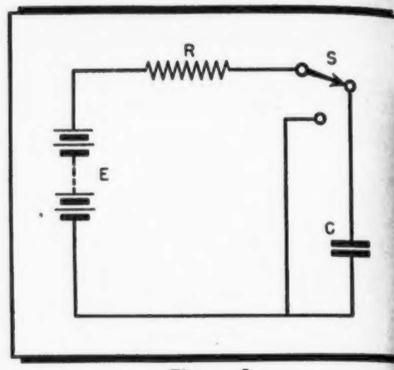

Figure 3

Several types of devices have been used to improve the wave shape, none of which can produce perfect linearity.

In the June, 1944 issue of *Wireless Engineer,* Arthur C. Clarke discusses such attempts at correction and offers several suggestions for theoretically perfect circuits. The article is entitled "Linearity Circuits."

In analyzing circuits already used, and circuits believed practical, the author discusses the following possibilities:

a. The thyratron as an automatic switching device which discharges a condenser when the voltage across it has reached a certain value.

b. The thyratron triggered by a negative pulse on the grid.

c. Auxiliary correcting devices, either ahead of or following the tube.

d. A series combination of inductances and resistances to limit the charging current into the condenser.

e. The pentode as a contant-current device to replace the resistance through which the condenser charges.

f. Negative feedback using the cathode follower with a triode.

g. Feedback using the "Bedford" circuit producing variable linearity which can be controlled and corrected in subsequent stages.

None of the above methods can produce perfect linearity because so far it has been assumed that all circuit components, including tubes, are linear devices. Whenever the charging current is proportional to the driving voltage an exponential output is obtained.

"Once an exponential wave had been produced any subsequent linear circuits can only differentiate it or integrate it—and the differential or integral of an exponential function is still exponential."

a. The simple time base is illustrated in *Fig. 3.* The voltage source E charges the condenser through resistance R in accordance with the formula $Vc = E(1 - \epsilon^{-t/CR})$, where Vc is the voltage across the condenser at any

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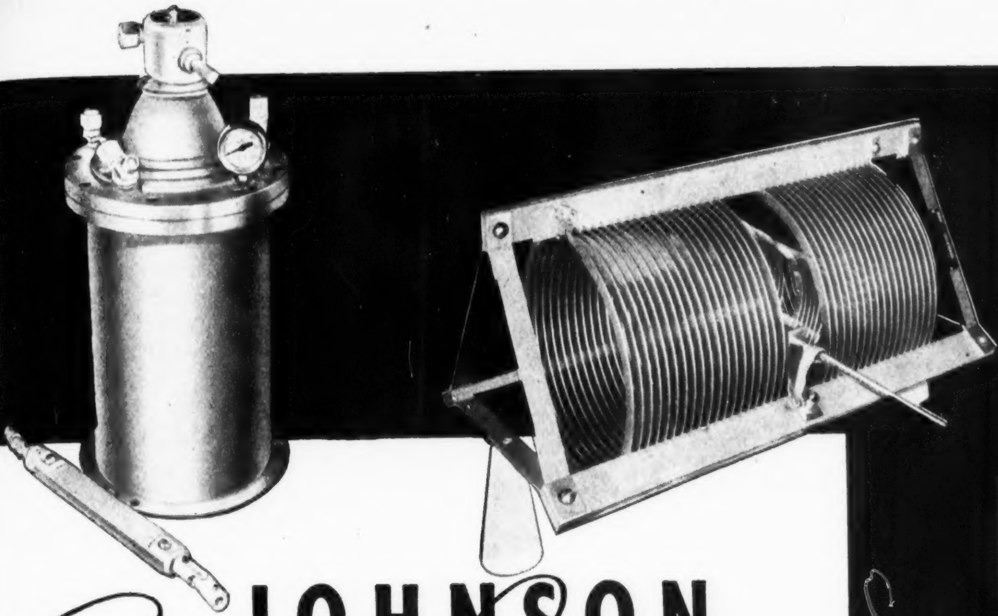

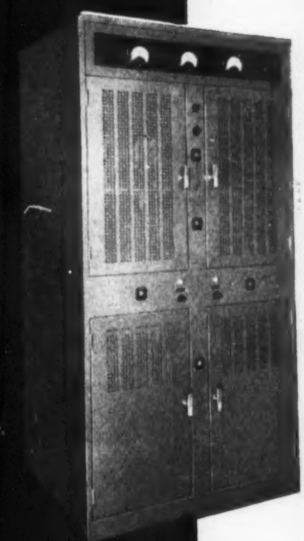

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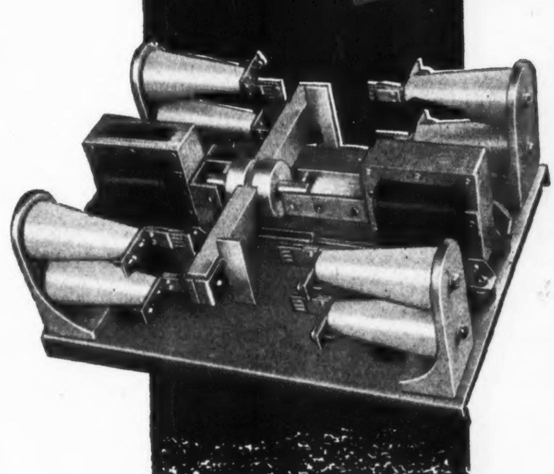

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instant. This formula gives an exponential curve starting at 0. The rate of rise depends upon time constant *CR*.

Switch S, which may be a gas triode, is employed to discharge the condenser at a certain time. The result is a saw-toothed wave as in *Fig. 4*. In practice the peak never quite reaches *E* because ordinarily the switch triggers before

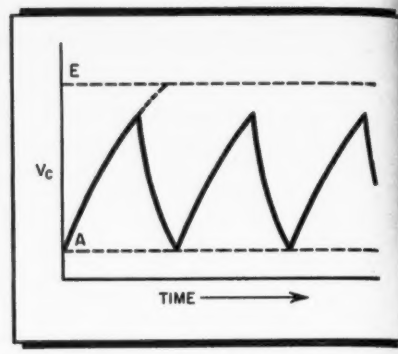

Figure 4

the condenser is fully charged. This tends to improve the linearity by making use of the nearly straight-rise portion of the curve. The voltage never quite drops to zero because of the internal resistance of the tube.

The trigger circuit with tube as a switch is shown in *Fig. 5*.

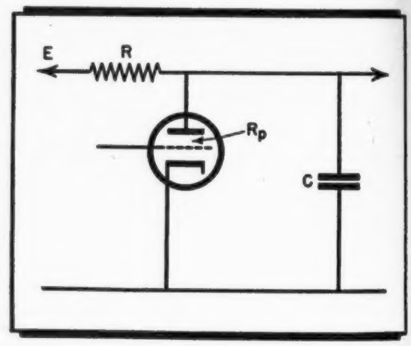

Figure 5

b. The tube may be made to act as a switch when a negative pulse is applied to the grid. The tube is driven to cut-off in any time sequence desired.

The author finds that, using *Fig. 4*, the point *A* gives a voltage value of $ERp/(R+Rp)$, the value to which the voltage falls when the condenser is discharged. This value will be almost zero when $Rp \ll R$. The peak will or will not reach *E* depending on the duration of the pulse and the time constant *RC*.

The author describes the above as an "integrating" circuit since the input pulse produces a saw-tooth output. The integral of a square wave is triangular.

A "differentiating" circuit is one in which the output is the differential of

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the input. If the output of *Fig. 6* is taken across resistance R it appears as a series of positive and negative pulses of theoretically infinite amplitude with an instantaneous wave front.

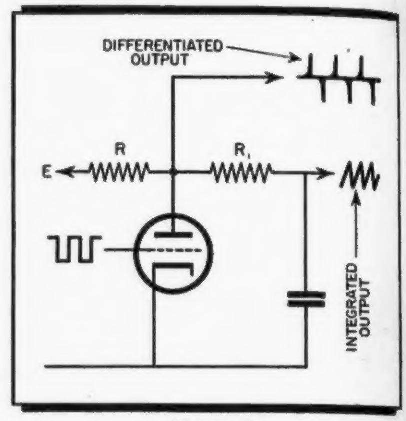

Figure 6

c. An auxiliary correcting circuit following the tube is shown in *Fig. 7*.

The circuit is in accordance with the expression: $E = (i + i_1)R + 1/c\int i_1dt + R_1i_1$. This has a solution of the form $i_1 = Ae^{\lambda_1 t} + Be^{\lambda_2 t}$. The output voltage across R_1 and C_1 is $v = i_1R_1 + \frac{1}{C_1}\int i_1dt$, which gives $v = E + A_1e^{\lambda_1 t} - A_2e^{\lambda_2 t}$, where A_1, A_2, λ_1, and λ_2 involve circuit constants C, R, R_1, and C_1, and initial conditions.

It is shown that $\lambda 1$ and $\lambda 2$ are real negative quantities and that $\lambda 1 \neq \lambda 2$. Although the above equation shows that the combination of exponential

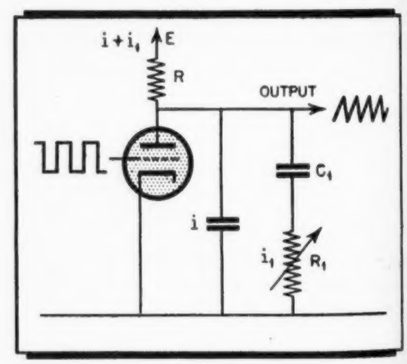

Figure 7

functions means that the voltage can rise to its final value E in an infinite number of ways, no combination of circuit constants can make it linear.

Nevertheless the auxiliary circuit can produce a slight improvement in linearity, particularly at the start of the voltage rise.

A form of auxiliary circuit in which the integrating circuit precedes the

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tube and the correcting network which follows is illustrated in *Fig. 8.*

The integrating circuit and tube deliver an exponential wave form to the correcting network, which gives some slight improvement. The output voltage is given as $v = K + A_1e^{-\lambda_1 t} + A_2e^{-\lambda_2 t}$ which is similar to that obtained for the circuit of *Fig. 7.*

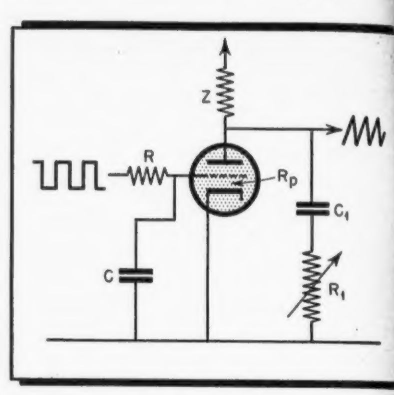

Figure 8

d. The use of inductances, as in Blumlein's time base, is analyzed with the conclusion that only an infinite number of inductances can produce a linear saw tooth, since there are an infinite number of frequencies in the wave.

e. The constant-current pentode is another possible linearity device. Provided the voltage on the pentode is not allowed to fall below the knee of the plate voltage-plant current characteristic, the current remains constant and the output is nearly linear up to 80-90% of the supply voltage.

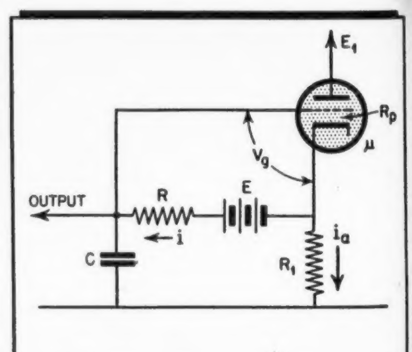

Figure 9

f. In a cathode follower the potential difference between the grid and the cathode remains almost constant so that an almost constant current must flow through *R* in *Fig. 9,* and *C* must charge up linearly.

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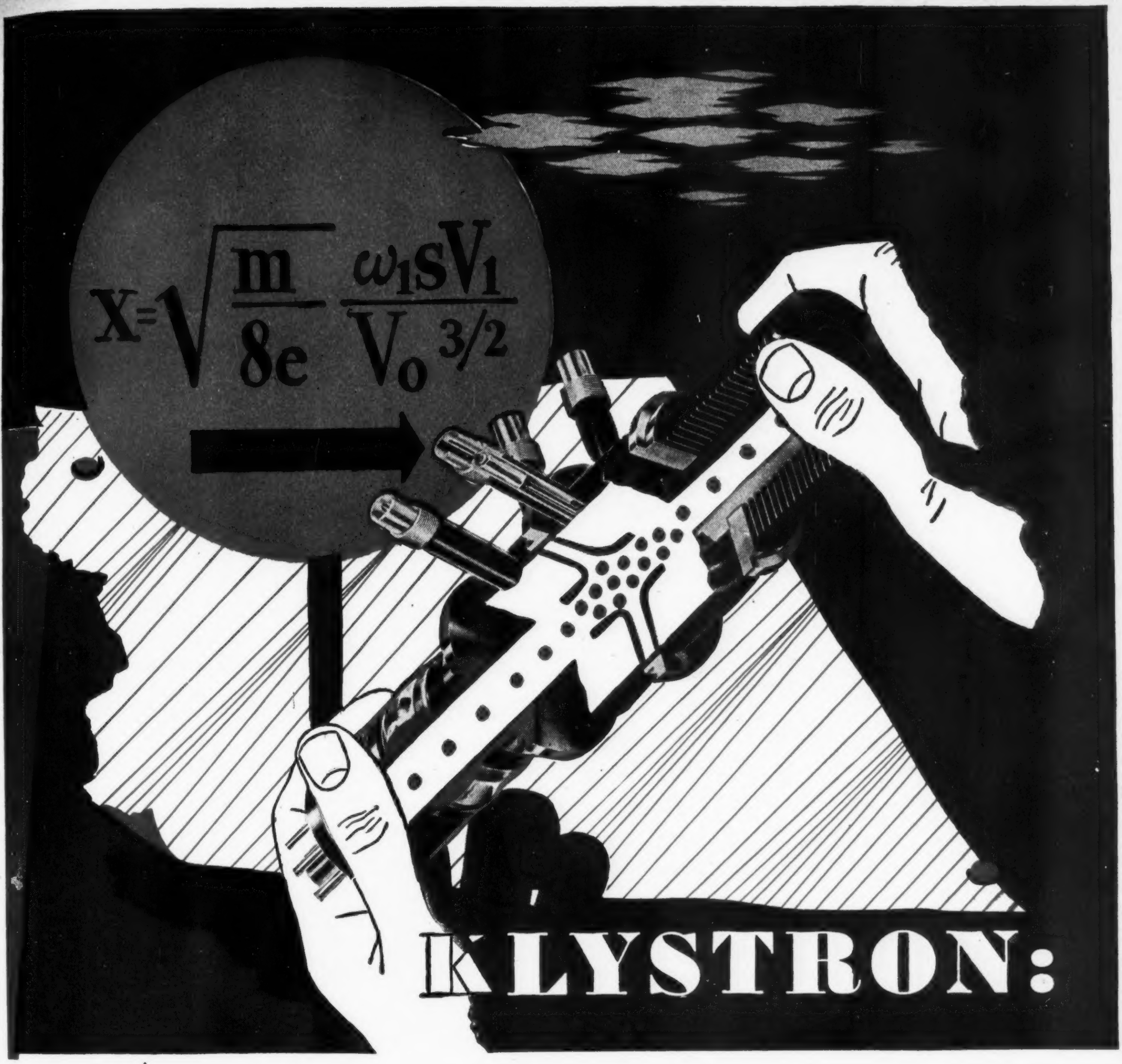

Mathematically, here's the inside story

THE FORMULA in the picture above is an expression of *bunching* as it takes place in the Klystron tube.

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In this circuit $Vg = E - iR$

$$E = i(R+R_1) - i_aR_1 + \frac{1}{c}\int idt$$

$$i_a = \frac{E_1 + \mu Vg}{Rp + R_1}$$

These equations, treated simultaneously, yield an output voltage equation

$$(E + \mu E/2 + E_1/2)\ (1 - e^{-\frac{t}{ac}})$$

in which a is a constant involving R, R_1, μ, and Rp. This is an exponential function similar to that of *Fig. 3*. However, since μ may be very high, the effective charging voltage can be several hundred times E, and if the output condenser operates only on the straight section of the wave, the output will be nearly linear.

g. Bedford's circuit employs a charging pentode V_1 in *Fig. 10*. As the voltage falls on the plate of *V1*, the grid of *V2* and point *A* will also fall in

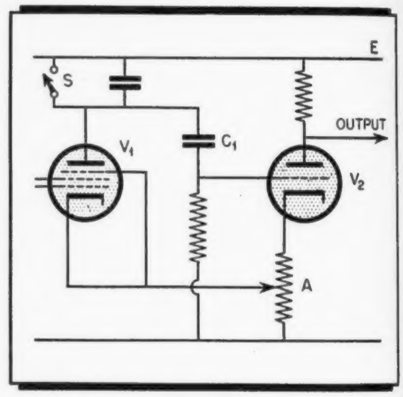

Figure 10

potential. The voltage across *V1* remains nearly constant so that the linearity of the output is improved. The position *A* may be varied so that near-linearity may be obtained in many ways. Perfect linearity is not possible.

In addition to the above more or less practical circuits the author has suggested three types of theoretical devices which may be capable of producing a purely linear output voltage, as follows:

a. Non-linear impedances.
b. Integrating amplifiers.
c. Logarithmic amplifiers.

a. For a constant current to flow through an impedance in series with a power source the relation would be $Z = kE$, in which the impedance is directly proportional to the voltage. Such an impedance does not appear reasonable to expect.

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However, for an impedance and a resistor in series, as in *Fig. 11*, there would be the relation $E = (I + i)R + iZ$. If I is to be constant, it must equal E/R, from initial conditions with the condenser uncharged. So that $E = (E/R + L)R + iZ$. From this expression $R = -Z$. The above implies the use of a tube circuit employing negative resistance independent of frequency.

b. It is now supposed that there is a two-stage amplifier with an integrating circuit between stages. The output triangular wave can be fed back through an attenuator into the input square wave, so that the input becomes a triangular wave superimposed upon a square wave.

The square wave component will produce the constant current through the resistance in the integrating circuit and the triangular wave will appear across the output condenser of the integrating circuit. It is stated that with proper adjustment of the feedback, an almost perfectly linear output can be obtained.

c. A non-linear amplifying tube must have a variable μ. Such tubes are manufactured and it is suggested that

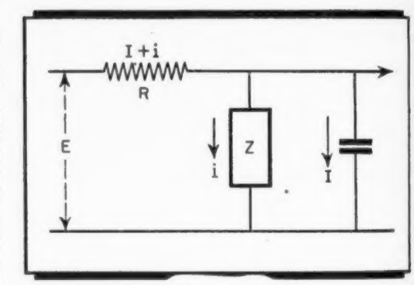

Figure 11

were a tube to be selected having the proper logarithmic amplifying characteristic the theoretically perfect output would be obtained. Such a tube may have to be designed.

The amplification factor of such a tube would be as follows:

$$\mu = -\frac{K}{\lambda Z_1} \cdot \frac{1}{e_g} \log\left(1 - \frac{e_g}{E}\right)$$

in which e_g is the grid input voltage from the expression $e = E(1 - e^{-\lambda t})$, $Z_1 = Z/(Z + Rp)$, where Z is the plate load impedance and Rp is the tube plate resistance, and k and λ are constants.

A graph of this equation appears in *Fig. 12*.

The equation becomes indeterminate for $e_g = 0$ so that the expression $\log(1 - e_g/E)$ was expanded to obtain the

[*Continued on page 18*]

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[*Continued from page 16*]

value $\mu = k/\lambda\ EZ_1$ when $e_g = 0$. This quantity was placed equal to unity in *Fig. 12.* The curve shown is an arbitrary one based on fixed values of k, λ, Z, $Z1$, and E, but is similar in form to that of the i_p—V_g characteristic of a variable—μ tube.

PENTODES AS A-F AMPLIFIERS

★ The disadvantages of triodes as resistance-coupled amplifiers have led to the use of pentodes, giving greater amplification and lower input capacity to the preceding stage.

The somewhat higher harmonic distortion often developed in pentode operation can be reduced provided good circuit design practice is followed. Some recommendations are given in an article entitled "R-F Pentodes as A-F Amplifiers" appearing in the July, 1944 issue of *Wireless World.* The author is S. W. Amos.

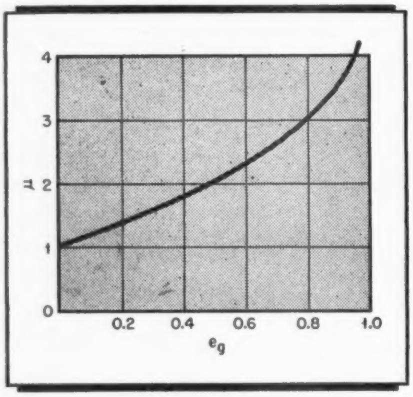
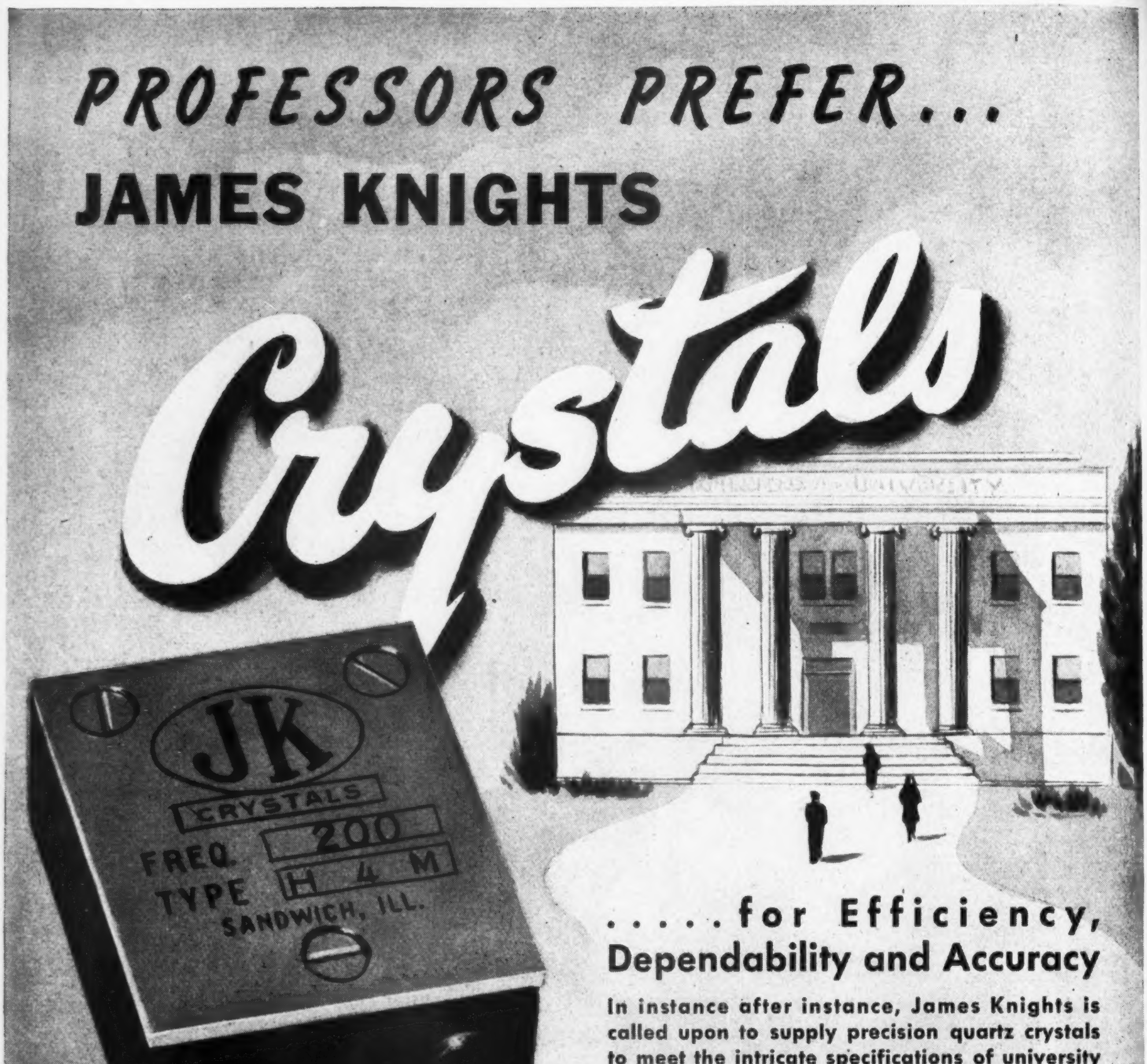


Figure 12

The expression for stage amplification is given as $G = \dfrac{\mu R}{R + Rp}$, where μ = tube amplification factor, R = load resistance, and Rp = plate resistance of the tube. The maximum gain approaches μ as a limit when the load resistance is large compared to the plate resistance of the tube. This is illustrated in *Fig. 15.*

An r-f amplifier, such as the 6J7, with a plate resistance of 1 megohm, acts as a constant-current generator and should therefore be used only with purely resistive loads for good frequency response. The amplification factor is many times that of a triode.

In *Fig. 13,* showing the basic *R-C* coupled r-f pentode as an a-f amplifier, it is noted that the screen potential, *Esg,* must not gresatly exceed the quiescent value of the plate potential, *Ep.* For a load resistance of 100,000 ohms a value of 300,000 ohms is given for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Design Theory of Loss-Less WAVE GUIDES

ANTHONY B. GIORDANO

Polytechnic Institute of Brooklyn

A rigorous mathematical analysis of wave guides is presented. Charts showing the cut-off wavelengths and attenuation constants of rectangular and circular wave guides are included

THE present trend in the realm of electromagnetic waves is the utilization of wavelengths shorter than 30 centimeters, or frequencies above 1000 megacycles per second. The former have been termed microwaves and the latter ultra-high frequencies. Line-of-sight propagation of electromagnetic waves, a broadening of the communication frequency spectrum, and a reduction in the physical size of equipment are all consequences of the application of microwaves.

In recent years, hollow tube conductors have been investigated as a means of guiding signals or intelligence. They are commonly known as wave guides, and may possess circular or rectangular cross-sections, as well as elliptical cross-sections which are, essentially, distorted circular cross-sections.

Since the wave guide conveys microwaves from a source to a place of use, it performs the same task as the coaxial transmission line. However, the wave guide performs its function without the need of an inner conductor, which is an essential part of the coaxial transmission line. Thus, the mechanical difficulties encountered in constructing coaxial lines as the warelength is shortened may be eliminated by using wave guides.

In brief, a hollow conducting tube acts as a high-pass filter of electromagnetic field patterns. The field patterns which exist within a wave guide are known as field modes. Each field mode possesses its own cut-off wavelength as well as its own propagation constant.

Emphasis on the relationship between cross-section dimensions and the wavelength of the source of excitation is required for the proper design of wave guides. If the wavelength of the source is slightly higher than the cut-off wavelengths of the field modes, the modes generated are attenuated in the wave guide, each mode having a different rate of attenuation. If the exciting wavelength is lower than the cut-off wavelengths of a few of the modes, then these modes will propagate and all others will attenuate. However, it is possible to generate one field mode by selecting a particular mode launcher. In general, the wave guide becomes a low-loss transmission system of electromagnetic waves.

General Method of Analysis

The mathematical treatment of wave guides involves solving the fundamental differential equations of the electromagnetic theory as postulated by Maxwell. The outline of the method is as follows:

1. Assume that a perfect dielectric occupies the entire inner region of the wave guide.
2. Assume that the metal has infinite conductivity, which intimates a loss-free system. This is physically realized by using metals of very high conductivities and short lengths of wave guides.
3. Solve Maxwell's source-free differential equations for the most general solution of the electromagnetic field in cylindrical coordinates for the circular wave guide or in rectangular coordinates for the rectangular wave guide. The proper choice of coordinates is an aid to simplification. The mathematical treatment is usually carried out in complex notation; *the imaginary parts of the complex space-time components of the electromagnetic fields to be discussed will represent the real components of the electromagnetic fields.*
4. The most general solution of the electromagnetic field reveals the existence of an infinite number of electromagnetic field patterns.
5. Substitute boundary conditions relating to the configuration of the wave guide into this general solution. The resulting equations will yield those

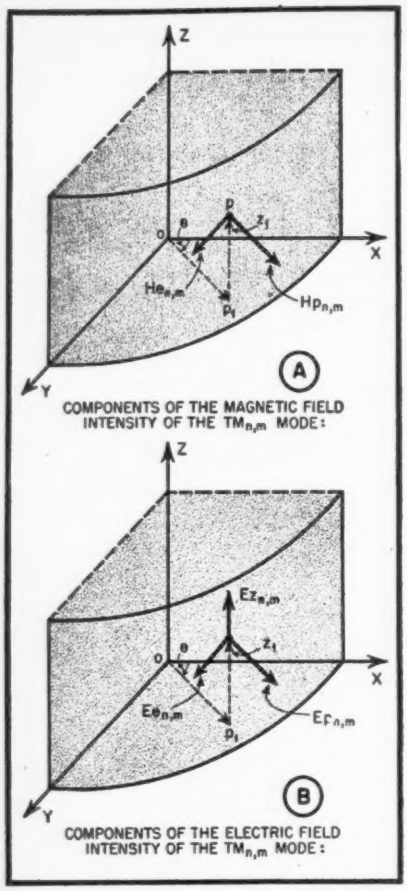

Fig. 1. Relative directions of the field components of the $TM_{n,m}$ mode of circular wave guides in cylindrical coordinates; θ, ρ, and z. (Propagation along Z axis)

electromagnetic field patterns which can exist within the wave guide. Each field pattern or mode is grouped as being either *Transverse Magnetic* or *Transverse Electric.*

6. *Transverse Magnetic* fields are those electromagnetic field patterns which have only a component of the electric field intensity lying along the longitudinal or propagation axis. These are often known as $TM_{n,m}$ fields or $TM_{n,m}$ modes or $E_{n,m}$ modes. (Refer to *Figs. 1* and *3.*)

7. Those electromagnetic field patterns which possess only a component of the magnetic field intensity along the propagation axis are known as *Transverse Electric* fields or $TE_{n,m}$ fields or $TE_{n,m}$ modes or $H_{n,m}$ modes. (Refer to *Figs. 2* and *4*).

8. The component field vectors shown in *Figs. 1, 2, 3,* and *4* vary with time and space.

Description of Symbols

The symbols to be used have the following meanings:

$H_{\theta n,m}$; $H_{\rho n,m}$; $H_{zn,m}$ = complex space-time components of the magnetic field intensity of the *n,m* mode in a circular wave guide expressed in amperes per centimeter.

$E_{\theta n,m}$; $E_{\rho n,m}$; $E_{zn,m}$ = complex space-time components of the electric field intensity of the *n,m* mode in a circular wave guide in volts per centimeter.

$H_{xn,m}$; $H_{yn,m}$; $H_{zn,m}$ = complex space-time components of the magnetic field intensity of the *n,m* mode in a rectangular wave guide in amperes per centimeter.

$E_{xn,m}$; $E_{yn,m}$; $E_{zn,m}$ = complex space-time components of the electric field intensity of the *n,m* mode in a rectangular wave guide in volts per centimeter.

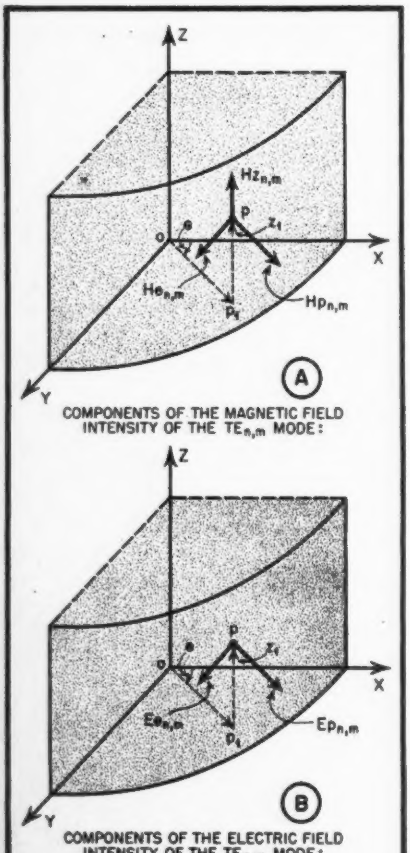

Fig. 2. Relative directions of the field components of the $TE_{n,m}$ mode of circular wave guides in cylindrical coordinates; θ, ρ, and z. (Propagation along Z axis).

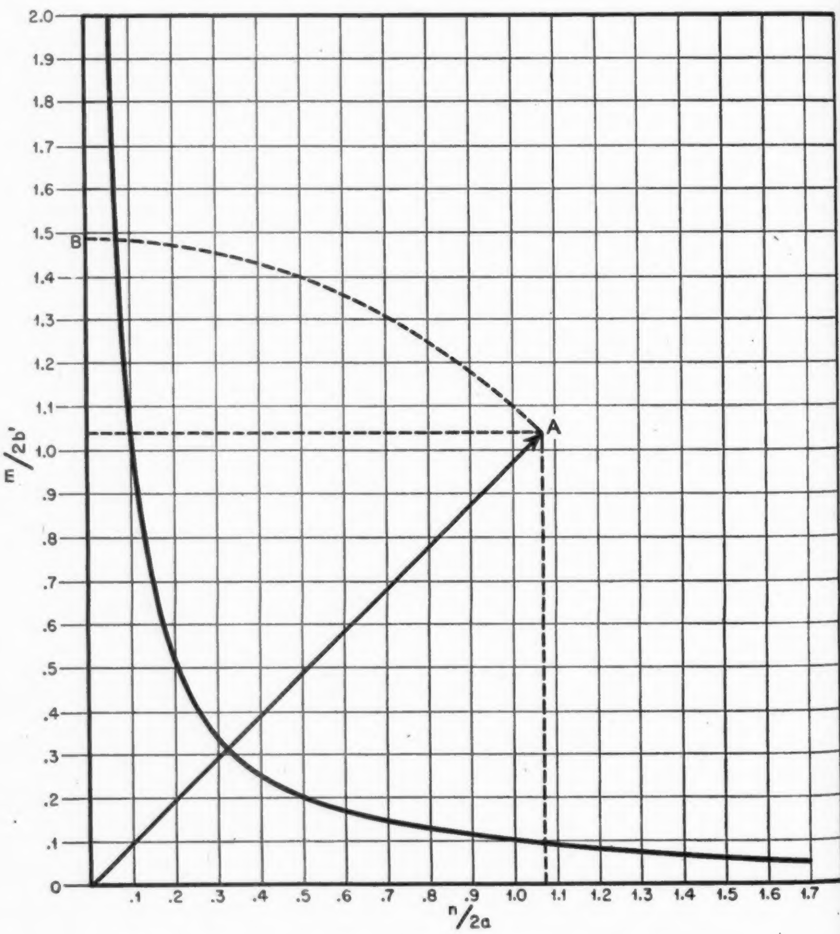

Fig. 6. To obtain the cut-off wavelength of an air-filled rectangular wave guide; for given values of *m*, *n*, *a* cm., *b* cm., plot point *A*. Draw line *OA*. Draw arc *AB* with *OA* as the radius. From the curve, for the ordinate value of *B*, find the corresponding abscissa value. The abscissa value multiplied by 10 yields the cut-off wavelength of the *n,m* mode in centimeters.

$A_{n,m}$; $B_{n,m}$; $C_{n,m}$; $D_{n,m}$ = boundary complex constants of the n,m mode at the input and output extremities of the wave-guide. They depend upon the mode and the wave guide launching and receiving systems.

$J_n\,[(k_{n,m})(\rho)]$ = Bessel's function of the first kind, order n.

$J'_n\,[(k'_{n,m})(\rho)]$ = first derivative of Bessel's function of the first kind, order n.

ρ = variable along the radius of the circular wave guide and varies from O to b, where b is the inner radius of the circular wave-guide in centimeters.

$X_{n,m} = (k_{n,m})(b)$ = argument of $J_n\,[(k_{n,m})(\rho)]$ when $\rho = b$.

$X'_{n,m} = (k'_{n,m})(b)$ = argument of $J_n'\,[(k'_{n,m})(\rho)]$ when $\rho = b$.

Xa = symbol which represents either $X_{n,m}$ or $X'_{n,m}$ and is used in conjunction with the design curves.

$\omega = 2\pi f$ = angular velocity of the exciting source, where f is the excitation frequency in cycles per second.

$\Delta = \dfrac{10^{-11}}{36\pi}\,\epsilon$ = absolute permittivity of the medium in farads per centimeter, where ϵ is the dielectric constant of the medium. For air, $\epsilon = 1$.

$\Pi = 4\pi\cdot10^{-9}\,\mu$ = absolute permeability of the medium in henry per centimeter, where μ is the relative permeability of the medium. For air, $\mu = 1$.

$\Delta\Pi = \dfrac{\epsilon\mu}{C^2}$, where C = speed of light in free space or air in centimeters per second.

$\gamma_{n,m} = \alpha_{n,m} + j\,B_{n,m}$ = propagation constant of the $TM_{n,m}$ mode.

$\gamma'_{n,m} = \alpha'_{n,m} + j\,B'_{n,m}$ = propagation constant of the $TE_{n,m}$ mode.

$\alpha_{n,m}$ = attenuation constant of the $TM_{n,m}$ mode in nepers per centimeter.

$\alpha'_{n,m}$ = attenuation constant of the $TE_{n,m}$ mode in nepers per centimeter.

α_e = attenuation constant of the n,m mode in db per centimeter. It is a general symbol used with the design curves.

$B_{n,m} = \dfrac{2\pi}{\lambda_{n,m}}$ = phase constant of the $TM_{n,m}$ mode in radians per centimeter, measured in the wave guide.

$B'_{n,m} = \dfrac{2\pi}{\lambda'_{n,m}}$ = phase constant of the $TE_{n,m}$ mode in radians per centimeter, measured in the wave guide.

λ = wavelength of the exciting source measured in free space or air, in centimeters.

$\lambda_{n,m}$ = wavelength of the $TM_{n,m}$ mode measured in the wave guide in centimeters.

$\lambda'_{n,m}$ = wavelength of the $TE_{n,m}$ mode measured in the wave guide in centimeters.

$(\lambda_{n,m})^c$ = the cut-off wavelength of the $TM_{n,m}$ mode referred to free space or air.

$(\lambda'_{n,m})^c$ = the cut-off wavelength of the $TE_{n,m}$ mode referred to free space or air.

λ_c = general symbol for the cut-off wavelength of the n,m mode.

b' = the inner dimension of the rectangular wave guide measured in centimeters along the x-axis.

a = the inner dimension of the rectangular wave guide measured in centimeters along the y-axis.

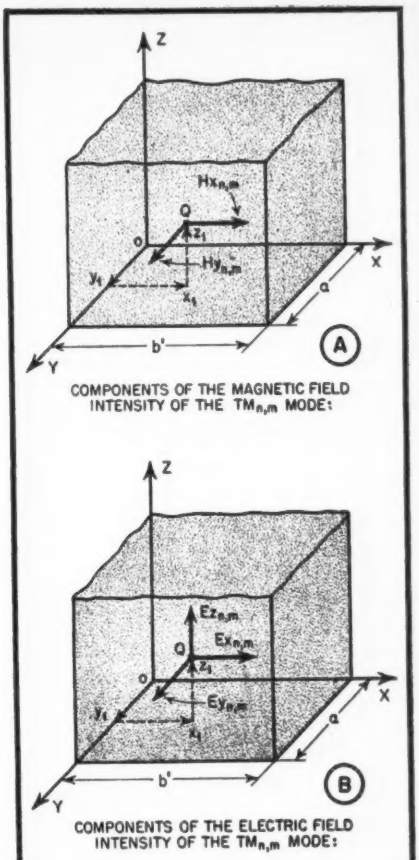

Fig. 3. Relative directions of the field components of the $TM_{n,m}$ mode of rectangular wave guides in rectangular coordinates; x, y, and z. (Propagation along Z axis).

The Circular Wave Guide

For an arbitrarily terminated circular wave guide, the complex space-time components of the $TM_{n,m}$ are given in 1:1 to 1:5 inc.

The term $B_{n,m}\,\epsilon^{+\gamma_{n,m}z}$ is indicative of the reflection caused by the arbitrary termination. If the wave-guide is ideally terminated, this term reduces to zero.

The metallic conductivity will be assumed to be infinite. As a consequence,

1-6: $E\theta_{n,m} = Ez_{n,m} = 0$, when $\rho = b$.

From equation 1-2 and 1-3, this condition is satisfied only when

1-7: $J_n\,[(k_{n,m})(b)] = J_n\,(X_{n,m}) = 0$.

There are an infinite number of values of $X_{n,m}$ which make this possible. The

1-1: $E\rho_{n,m} = [A_{n,m}\,\epsilon^{-\gamma_{n,m}z} - B_{n,m}\,\epsilon^{+\gamma_{n,m}z}]\;[C_{n,m}\cos(n\theta) + D_{n,m}\sin(n\theta)]\;[(k_{n,m})\,(\gamma_{n,m})\,(\epsilon^{+j\omega t})]\;\{-J'_n\,[(k_{n,m})\,(\rho)]\}$

1-2: $E\theta_{n,m} = [A_{n,m}\,\epsilon^{-\gamma_{n,m}z} - B_{n,m}\,\epsilon^{+\gamma_{n,m}z}]\;[C_{n,m}\sin(n\theta) - D_{n,m}\cos(n\theta)]\;[(\gamma_{n,m})\,\left(\frac{n}{\rho}\right)\,(\epsilon^{+j\omega t})]\;\{J_n\,[(k_{n,m})\,(\rho)]\}$

1-3: $Ez_{n,m} = [A_{n,m}\,\epsilon^{-\gamma_{n,m}z} + B_{n,m}\,\epsilon^{+\gamma_{n,m}z}]\;[C_{n,m}\cos(n\theta) + D_{n,m}\sin(n\theta)]\;[(k_{n,m})^2\,(\epsilon^{+j\omega t})]\;\{J_n\,[(k_{n,m})\,(\rho)]\}$

1-4: $H\rho_{n,m} = [A_{n,m}\,\epsilon^{-\gamma_{n,m}z} + B_{n,m}\,\epsilon^{+\gamma_{n,m}z}]\;[C_{n,m}\sin(n\theta) - D_{n,m}\cos(n\theta)]\;[(-j\omega\Delta)\,\left(\frac{n}{\rho}\right)\,(\epsilon^{+j\omega t})]\;\{J_n\,[(k_{n,m})\,(\rho)]\}$

1-5: $H\theta_{n,m} = [A_{n,m}\,\epsilon^{-\gamma_{n,m}z} + B_{n,m}\,\epsilon^{+\gamma_{n,m}z}]\;[C_{n,m}\cos(n\theta) + D_{n,m}\sin(n\theta)]\;[(+j\omega\Delta)\,(k_{n,m})\,(\epsilon^{+j\omega t})]\;\{-J'_n\,[(k_{n,m})\,(\rho)]\}$

$$2\text{-}1:\ H\rho_{n,m} = [A_{n,m}\,\epsilon^{-\gamma'_{n,m}z} - B_{n,m}\,\epsilon^{+\gamma'_{n,m}z}]\ C_{n,m}\cos(n\theta) + D_{n,m}\sin(n\theta)]\ [(k'_{n,m})\ (\gamma'_{n,m})\ (\epsilon^{+j\omega t})]\ \{-J'_n\,[(k'_{n,m})\ (\rho)]\}$$

$$2\text{-}2:\ H\theta_{n,m} = [A_{n,m}\,\epsilon^{-\gamma'_{n,m}z} - B_{n,m}\,\epsilon^{+\gamma'_{n,m}z}]\ [C_{n,m}\sin(n\theta) - D_{n,m}\cos(n\theta)]\ [\ (\gamma'_{n,m})\ \left(\frac{n}{\rho}\right)\ (\epsilon^{+j\omega t})\ ]\ \{\ J_n\,[(k'_{n,m})\ (\rho)]\}$$

$$2\text{-}3:\ Hz_{n,m} = [A_{n,m}\,\epsilon^{-\gamma'_{n,m}z} + B_{n,m}\,\epsilon^{+\gamma'_{n,m}z}]\ [C_{n,m}\cos(n\theta) + D_{n,m}\sin(n\theta)]\ [\ (k'_{n,m})^2\ (\epsilon^{+j\omega t})\ ]\ \{\ J_n\,[(k'_{n,m})\ (\rho)]\}$$

$$2\text{-}4:\ E\rho_{n,m} = [A_{n,m}\,\epsilon^{-\gamma'_{n,m}z} + B_{n,m}\,\epsilon^{+\gamma'_{n,m}z}]\ [C_{n,m}\sin(n\theta) - D_{n,m}\cos(n\theta)]\ [(\ j\omega\pi)\ \left(\frac{n}{\rho}\right)\ (\epsilon^{+j\omega t})\ ]\ \{\ J_n\,[(k'_{n,m})\ (\rho)]\}$$

$$2\text{-}5:\ E\theta_{n,m} = [A_{n,m}\,\epsilon^{-\gamma'_{n,m}z} + B_{n,m}\,\epsilon^{+\gamma'_{n,m}z}]\ [C_{n,m}\cos(n\theta) + D_{n,m}\sin(n\theta)]\ [(-j\omega\pi)\ (k'_{n,m})\ (\epsilon^{+j\omega t})]\ \{-J'_n\,[(k'_{n,m})\ (\rho)]\}$$

important values of $X_{n,m}$ are listed in *Table 1.*

TABLE 1

$n \backslash m$	1	2	3	4
0	2.4	5.52	8.65	11.79
1	3.83	7.02	10.17	13.32
2	5.14	8.42	11.62	14.8
3	6.38	9.76	13.02	16.22

Referring to equation 1-1, the subscript n is associated with sin $(n\theta)$ or cos $(n\theta)$, where n represents the number of full cycles of field intensity variation which occur in going around the periphery of the wave guide. It is also the order number of Bessel's function of the first kind. The subscript m is the rank of the zero values of J_n $(X_{n,m})$. Thus X_{01} represents the argument of root value of the Bessel function of the first kind, *order zero,* which produces the *first zero* value of Jn $(X_{n,m})$ or a zero of rank 1.

From the solution of Maxwell's equations, the propagation constant of the $TM_{n,m}$ mode evaluates to be:

$$1\text{-}8:\ \gamma_{n,m} = \sqrt{(k_{n,m})^2 - \omega^2\,(\Delta\Pi)} = \sqrt{\left(k_{n,m}\right)^2 - \left(\frac{2\pi}{\lambda}\sqrt{\epsilon\mu}\right)^2},$$

where $k_{n,m} = \dfrac{X_{n,m}}{b}.$

Thus, when

a). $k_{n,m} = \dfrac{2\pi}{\lambda}\sqrt{\epsilon\mu}$, cut-off of the $TM_{n,m}$ mode occurs.

Therefore,

$$1\text{-}9:\ (\lambda_{n,m})^c = \frac{2\pi}{k_{n,m}}\sqrt{\epsilon\mu} = \frac{2\pi b}{X_{n,m}}\sqrt{\epsilon\mu}$$

b). $k_{n,m} < \dfrac{2\pi}{\lambda}\sqrt{\epsilon\mu}$, propagation of the $TM_{n,m}$ mode occurs, so that,

$$\gamma_{n,m} = +j\sqrt{\left(\frac{2\pi}{\lambda}\sqrt{\epsilon\mu}\right)^2 - k^2_{n,m}}\ \text{or}$$

$$1\text{-}10:\ B_{n,m} = \sqrt{\left(\frac{2\pi}{\lambda}\sqrt{\epsilon\mu}\right)^2 - \left[\frac{2\pi\sqrt{\epsilon\mu}}{(\lambda_{n,m})^c}\right]^2},$$

since $\alpha_{n,m}$ is zero. From equation 1-10, therefore,

$$1\text{-}11:\ \lambda_{n,m} = \frac{\lambda}{\sqrt{\epsilon\mu}\sqrt{1 - \left[\dfrac{\lambda}{(\lambda_{n,m})^c}\right]^2}}$$

which indicates that the wavelength measured in the wave guide is longer than the excitation wavelength. This signifies a higher phase velocity of the mode.

c). $k_{n,m} > \dfrac{2\pi}{\lambda}\sqrt{\epsilon\mu}$, attenuation of the $TM_{n,m}$ mode occurs.

Thus, $\gamma_{n,m} =$

$$\sqrt{\left(\frac{X_{n,m}}{b}\right)^2 - \left(\frac{2\pi}{\lambda}\sqrt{\epsilon\mu}\right)^2}\ \text{or}$$

$$1\text{-}12:\ \alpha_{n,m} = 2\pi\sqrt{\left(\frac{X_{n,m}}{2\pi b}\right)^2 - \left(\frac{\sqrt{\epsilon\mu}}{\lambda}\right)^2}$$

since $B_{n,m} = 0$.

The $TM_{n,m}$ mode becomes a highly attenuated exponential field, the rate of attenuation being determined by $\alpha_{n,m}$.

The complex space-time components of the $TE_{n,m}$ mode in a circular wave guide are given in 2:1 to 2:5 inc.

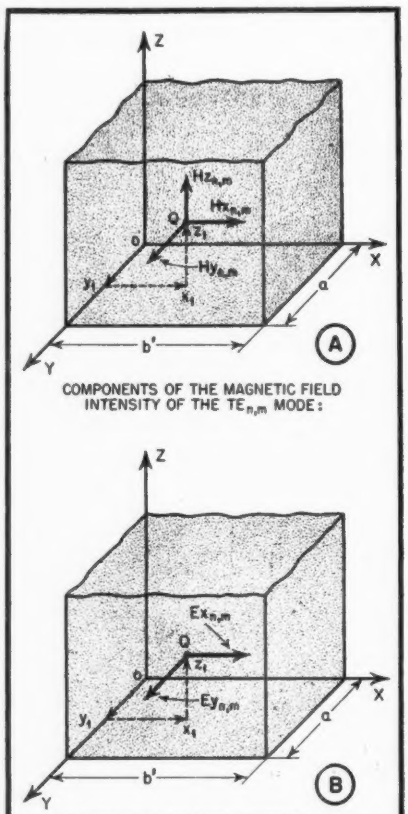

Fig. 4. Relative directions of the field components of the $TE_{n,m}$ mode of rectangular wave guides in rectangular coordinates; x, y, and z. (Propagation along Z axis).

The boundary condition that

2-6: $E\theta_{n,m} = 0$, when $\rho = b$, is now satisfied when

2-7: $J_n'\ (X'_{n,m}) = 0$. The important values of $X'_{n,m}$ are given by *Table 2.*

TABLE 2

n/m	1	2	3
0	3.83	7.02	10.17
1	1.84	5.33	8.54
2	3.06	6.71	9.97
3	4.20	8.02	11.35

The propagation constant of the $TE_{n,m}$ mode is

$$2\text{-}8:\ \gamma'_{n,m} = \sqrt{(k'_{n,m})^2 - (2\pi\sqrt{\epsilon\mu})^2},$$

where

$$k'_{n,m} = \frac{X'_{n,m}}{b}.$$

Therefore, the cut-off wavelength becomes

$$2\text{-}9:\ (\lambda'_{n,m})^c = \frac{2\pi}{k'_{n,m}}\sqrt{\epsilon\mu} = \frac{2\pi b}{X'_{n,m}}\sqrt{\epsilon\mu}$$

For propagation,

$$2\text{-}10:\ B'_{n,m} = \sqrt{\left(\frac{2\pi}{\lambda}\sqrt{\epsilon\mu}\right)^2 - \left[\frac{2\pi\sqrt{\epsilon\mu}}{(\lambda'_{n,m})^c}\right]^2}$$

or

$$2\text{-}11:\ \lambda'_{n,m} = \frac{\lambda}{\sqrt{\epsilon\mu}\sqrt{1 - \left[\dfrac{\lambda}{(\lambda'_{n,m})^c}\right]^2}}$$

For attenuation,

$$2\text{-}12:\ \alpha'_{n,m} = 2\pi\sqrt{\left(\frac{X'_{n,m}}{2\pi b}\right)^2 - \left(\frac{\sqrt{\epsilon\mu}}{\lambda}\right)^2}$$

An excitation source arbitrarily applied to a wave guide excites an infinite number of TM and TE modes. Some propagate and others attenuate. However, a superposition of all the modes existing in the wave guide yields the resultant wave guide electromagnetic field pattern. By selecting a proper launching device, a single mode can be made to exist in the wave guide. This has been admirably discussed by Southworth[1] and by Chu and Barrow.[2]

The Rectangular Wave Guide

The complex space-time components of the $TM_{n,m}$ mode established in a rectangular wave guide are:

For infinite conductivity of the metal, the boundary conditions become:

$Ex_{n,m} = 0$, when $y = 0$ or $y = a$;

and

$Ey_{n,m} = 0$, when $x = 0$ or $x = b'$

From equations 3-1 and 3-2, these conditions are satisfied when,

3-6: $\sin[(k_n)(a)] = 0$, for $Ex_{n,m} = 0$

3-7: $\sin[(l_m)(b')] = 0$, for $Ey_{n,m} = 0$

$$\text{3-1:}\quad Ex_{n,m} = (A_{n,m}\,\epsilon^{-\gamma_{n,m}z} - B_{n,m}\,\epsilon^{+\gamma_{n,m}z})\,[\sin[(k_n)(y)]\cdot\cos[(l_m)(x)]]\cdot[-(l_m)(\gamma_{n,m})(\epsilon^{+j\omega t})]$$

$$\text{3-2:}\quad Ey_{n,m} = (A_{n,m}\,\epsilon^{-\gamma_{n,m}z} - B_{n,m}\,\epsilon^{+\gamma_{n,m}z})\,[\sin[(l_m)(x)]\cdot\cos[(k_n)(y)]]\cdot[-(k_n)(\gamma_{n,m})(\epsilon^{+j\omega t})]$$

$$\text{3-3:}\quad Ez_{n,m} = (A_{n,m}\,\epsilon^{-\gamma_{n,m}z} + B_{n,m}\,\epsilon^{+\gamma_{n,m}z})\,[\sin[(k_n)(y)]\cdot\cos[(l_m)(x)]]\cdot[(k^2_n+l^2_m)(\epsilon^{+j\omega t})]$$

$$\text{3-4:}\quad Hx_{n,m} = (A_{n,m}\,\epsilon^{-\gamma_{n,m}z} + B_{n,m}\,\epsilon^{+\gamma_{n,m}z})\,[\sin[(l_m)(x)]\cdot\cos[(k_n)(y)]]\cdot[(+j\omega\Delta)(k_n)(\epsilon^{+j\omega t})]$$

$$\text{3-5:}\quad Hy_{n,m} = (A_{n,m}\,\epsilon^{-\gamma_{n,m}z} + B_{n,m}\,\epsilon^{+\gamma_{n,m}z})\,[\sin[(k_n)(y)]\cdot\cos[(l_m)(x)]]\cdot[(-j\omega\Delta)(l_m)(\epsilon^{+j\omega t})]$$

Therefore, $k_n = \frac{n\pi}{a}$ and $l_m = \frac{m\pi}{b'}$ and the propagation constant becomes,

3-8: $\gamma_{n,m} =$

$$\sqrt{\left(\frac{n\pi}{a}\right)^2 + \left(\frac{m\pi}{b'}\right)^2 - \left(\frac{2\pi}{\lambda}\sqrt{\epsilon\mu}\right)^2}$$

Thus,

3-9: $(\lambda_{n,m})^c =$

$$\frac{\sqrt{\epsilon\mu}}{\sqrt{\left(\frac{n}{2a}\right)^2 + \left(\frac{m}{2b'}\right)^2}}$$

The subscript n is an integer representing the number of half cycles of field intensity variation which occur along the y-axis as y varies from o to a. The subscript m has the same significance along the x-axis as x varies from o to b'

For propagation,

3-10: $B_{n,m} =$

$$\sqrt{\left(\frac{2\pi}{\lambda}\sqrt{\epsilon\mu}\right)^2 - \left[\left(\frac{n\pi}{a}\right)^2 + \left(\frac{m\pi}{b'}\right)^2\right]}$$

and for attenuation,

3-11: $\alpha_{n,m} =$

$$\sqrt{\left[\left(\frac{n\pi}{a}\right)^2 + \left(\frac{m\pi}{b'}\right)\right]^2 - \left(\frac{2\pi}{\lambda}\sqrt{\epsilon\mu}\right)^2}$$

The E_{11} is the lowest order mode possible since modes of the type E_{oo}, $E_{n,o}$, and $E_{o,m}$ cannot exist, as is evident from the space-time components.

The complex space-time components of the TE modes created within a rectangular wave guide are deduced to be,

$$\text{4-1:}\quad Hx_{n,m} = (A_{n,m}\,\epsilon^{-\gamma'_{n,m}z} - B_{n,m}\,\epsilon^{+\gamma'_{n,m}z})\,[\sin[(k_n)(y)]\cdot\cos[(l_m)(x)]]\cdot[-(l_m)(\gamma'_{n,m})(\epsilon^{+j\omega t})]$$

$$\text{4-2:}\quad Hy_{n,m} = (A_{n,m}\,\epsilon^{-\gamma'_{n,m}z} - B_{n,m}\,\epsilon^{+\gamma'_{n,m}z})\,[\sin[(l_m)(x)]\cdot\cos[(k_n)(y)]]\cdot[-(k_n)(\gamma'_{n,m})(\epsilon^{+j\omega t})]$$

$$\text{4-3:}\quad Hz_{n,m} = (A_{n,m}\,\epsilon^{-\gamma'_{n,m}z} + B_{n,m}\,\epsilon^{+\gamma'_{n,m}z})\,[\sin[(k_n)(y)]\cdot\cos[(l_m)(x)]]\cdot[(k^2_n+l^2_m)(\epsilon^{+j\omega t})]$$

$$\text{4-4:}\quad Ex_{n,m} = (A_{n,m}\,\epsilon^{-\gamma'_{n,m}z} + B_{n,m}\,\epsilon^{+\gamma'_{n,m}z})\,[\sin[(l_m)(x)]\cdot\cos[(k_n)(y)]]\cdot[(+j\omega\pi)(k_n)(\epsilon^{+j\omega t})]$$

$$\text{4-5:}\quad Ey_{n,m} = (A_{n,m}\,\epsilon^{-\gamma'_{n,m}z} + B_{n,m}\,\epsilon^{+\gamma'_{n,m}z})\,[\sin[(k_n)(y)]\cdot\cos[(l_m)(x)]]\cdot[(-j\omega\pi)(l_m)(\epsilon^{+j\omega t})]$$

The boundary conditions of the TE modes are the same as those for the TM modes. As a consequence,

$$k_n = \frac{n\pi}{a} \text{ and } l_m = \frac{m\pi}{b'}.$$

Thus,

4-6: $(\lambda'_{n,m})^c =$

$$\frac{\sqrt{\epsilon\mu}}{\sqrt{\left(\frac{n}{2a}\right)^2 + \left(\frac{m}{2b'}\right)^2}}$$

When the mode propagates,

4-7: $B'_{n,m} =$

$$\sqrt{\left(\frac{2\pi}{\lambda}\sqrt{\epsilon\mu}\right)^2 - \left[\left(\frac{n\pi}{a}\right)^2 + \left(\frac{m\pi}{b'}\right)^2\right]}$$

and when it attenuates,

4-8: $\alpha'_{n,m} =$

$$\sqrt{\left[\left(\frac{n\pi}{a}\right)^2 + \left(\frac{m\pi}{b'}\right)^2 - \left(\frac{2\pi}{\lambda}\sqrt{\epsilon\mu}\right)^2\right.}$$

Except for H_{oo}, all the TE modes can exist.

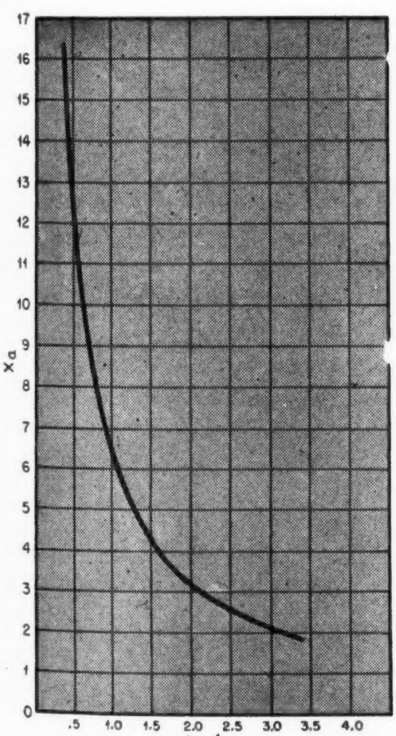

Fig. 5. To determine the cut-off wavelength, λ_c, of the n,m mode in an air-filled circular wave guide corresponding to radius b cm. and root value $X/_a$.

Design Curves for Air-Filled Wave Guides

The cut-off wavelengths of the TE and TM modes in a circular wave guide of a given radius can be ascertained from *Fig. 5*. For the rectangular waveguide, refer to *Fig. 6*.

The attenuation constants of either the TE or TM modes in a circular or rectangular wave guide are deduced from *Fig. 7*.

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1. G. C. Southworth, "Hyper-frequency Wave Guides." *Bell Sys. Tech. Journal*, Vol. 15, April, 1936.
2. Chu and Barrow, "Electromagnetic Waves in Hollow Metal Tubes of Rectangular Cross-Section." *Proc. I.R.E.*, Vol. 26, Dec., 1938.

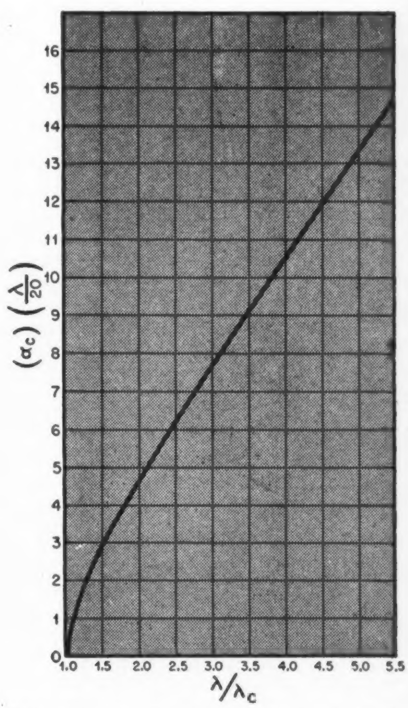

Fig. 7. To determine the attenuation stant α_c, in db per centimeter of the n,m mode in an air-filled circular or rectangular wave guide. For a given excitation wavelength, λ, and the cut-off wavelength of the n,m mode, λ_c, find the ordinate value corresponding to the ratio λ/λ_c. This ordinate value multiplied by $20/\lambda$ yields α_c.

H-F CRYSTAL OSCIL

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IT MAY BE said, in general, that the high frequencies have lacked in large measure the benefit of good frequency stability as compared to the lower frequencies under approximately ten megacycles where crystal control has been usefully applied. Whether this stability was needed from the transmitter source or for the control of the receiver circuits, crystal control between ten and fifteen megacycles has been the useful fringe for the fundamental type of oscillator crystal.

When crystal control is thought of for use at frequencies up to one hundred megacycles and over, multiplier stages and buffer amplifiers must be used for the accomplishment of the higher frequency crystal stability desired. It would be an advantage to be able to obtain a source of crystal-controlled high frequency voltage without the use of additional, and costly, auxiliary intermediate stages.

Interference

In the future, this reduction in the number of radio-frequency multiplications generated for a given frequency multiple desired will be necessary for the elimination of spurious interference to received signals. For example, the use of pretuned channels in f-m and television receiving equipment will be most convenient and, with the wider band widths employed in this type of service, it may be very troublesome to have harmonics of the base oscillator interefere with a portion of the higher f-m and, especially, television carriers.

This thinking, of course, assumes that conventional crystal oscillator circuits and crystal plates are used for this purpose. It is logical to assume that the availability and economic structure of the production of crystal plates will allow the full consideration of equipment designed for their advantages. In any event, as the services are extended to the higher frequencies, the possibility of continuing to utilize standard self-excited oscillators does not yield the frequency stability requirement so important in the assignment and allocation of the additional services to be accommodated as time goes on.

Crystal oscillator circuits are usually considered rather straightforward items in design and not unusual or difficult propositions. And so they may be for the equipment and frequencies normally encountered in past experiences. However, certain fundamental problems must be considered for the use of crystals in circuits of higher frequencies. The chief differences are found in the method and manner of vibration of the crystal to be used in high-frequency control. At the same time it may be expected that the oscillator circuit itself will be modified to more suitably satisfy the reactances found at the higher frequencies.

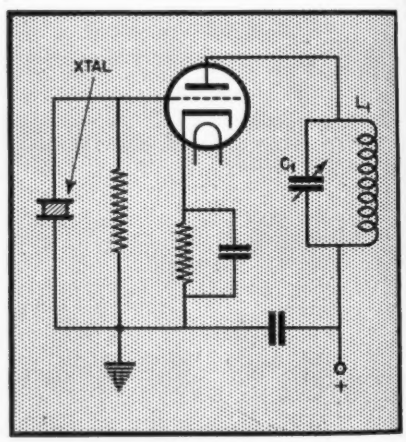


Fig. 1. Tuned plate crystal oscillator

Circuit Analysis

Fig. 1 illustrates a familiar crystal oscillator circuit in which the plate circuit elements *L1* and *C1* are arranged to vary the tuning of the fundamental frequency of the crystal element. *Fig. 2* illustrates the impedance network formed by the values associated in *Fig. 1* where

Z_{xtal} is the effective impedance of the crystal at its resonant frequency.

E_{go} is the radio frequency voltage measured between the grid and cathode.

SCILLATOR CIRCUITS

An analysis of high-frequency crystal oscillator circuits is given. A special circuit for high harmonic operation is discussed.

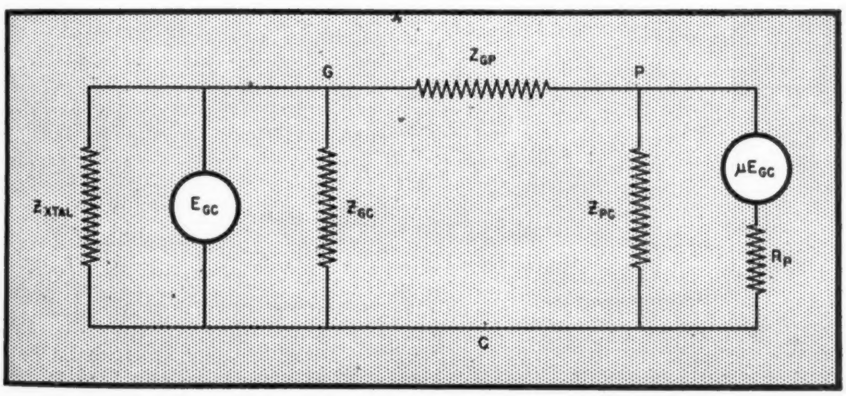


Fig. 2. Impedance network of tuned plate crystal oscillator.

Z_{gc} represents the impedance of the circuit between the grid and cathode, consisting of the inter-electrode capacity and circuit wiring. It should be noted that the impedance of the crystal is shown separately although it may be included with this value.

Z_{gp} represents the grid-to-plate impedance.

Z_{pc} is a measure of the plate-to-cathode impedance.

R_p is the plate resistance of the tube.

The circuit shown is to be considered as operating in the class A region as an oscillator with E_{gc} and μE_{gc} essentially 180 degrees out of phase. As the value of *C1* is altered in *Fig. 1* a region will be approached where an inductive plate load will be presented to the resonant frequency of the oscillator grid circuit and may start oscillation in the crystal shown in the circuit. The impedance Z_{pc} will be relatively low compared to the value to be found associated with Z_{gc}.

The current I_{pc} will be found to lag μE_{gc} and E_{pc} will be equal to μE_{go} minus $R_p\ I_{pc}$.

It can be seen that

$$E_{pc} = E_{gc} + E_{pg}$$

$$\text{so} \quad E_{gp} = Z_{gp}\ I_{gp}$$

$$\text{and} \quad I_{gp} = I_{gc}\ Z_{gc} = E_{gc}$$

When the plate circuit reactance is inductive, in this case Z_{pc}, and in the circuit shown, the coupling impedance Z_{gp} is capacitive, Z_{gc} will become a negative reactance and the effective resistance of the circuit looking from the crystal impedance will permit sustained oscillations to occur, provided the circuit parameters are so adjusted as to allow the proper phase relationship between E_{gc} and I_{pc} to be maintained.

At this point the crystal will assume control of the grid voltage and continue to vibrate alternately at the electromechanical frequency it has been designed for. The major electrical the dielectric capacity of the plate as well as the direct piezo-electric effect. The mechanical system, consisting of a discrete mass and stiffness, is electrically analogous to the inductance and capacity.

These are the useful crystal characteristics apart from the electrical equivalent conditions mentioned. This mechanical medium is coupled to the phase requirement of the oscillator proper through the piezo-electric coupling voltage generated by the potential supplied by the circuit. The value of this piezo-electric voltage in the circuit depends, in general, upon the method of mounting and exciting the crystal. Other variations, such as size and quality of the crystal and degree of skill used in the final adjustments, have a direct effect upon the worth of the crystal plate for high-frequency operation.

In *Fig. 3,* the piezo-electric coupling coefficient can be determined by the ratio of capacities given by

$$P = \frac{C3}{C1 + C2}$$

As the value of P diminishes the resonant frequency Fr and the anti-resonant frequency Fa will diminish in frequency separation also. See *Fig. 4.* This results in a smaller positive reactance region which will in turn limit the amplitude of the developed oscillator voltage.

Equivalent Circuit Values

In order to work intelligently with impedance values of the crystal element, a determination of the equivalent electrical values is in order. Equivalent circuit value measurements for a quartz crystal may be obtained by carefully following procedures of substituting values of known order in place of the crystal equivalent quantities. These electrical constants may be applied to the circuit analysis and permit a precise degree of planning for the design of crystal oscillator circuits. This will result in knowledge of the circulating crystal currents and the equivalent resonant frequency that will be obtained when a crystal of known electrical constants is used in the circuit.

The crystal manufacturer should be able to supply the equivalent circuit constants of his various units and thereby provide a set of values that are more easily coordinated with the equipment in which it must be used. This procedure will be ideal for matching exact frequency calibrations between circuits used at different locations and where carefully adjusted matched frequencies are required.

Measurements

For such measurements to mean much, the effects of crystal holders and associated mountings must be kept very uniform or variations of this type must be held to a minimum. The measurements can be obtained through the use of a variable radio-frequency energizing source from which the crystal under test is excited. The resonant frequency of the crystal is observed by checking the maximum deflection of a suitably connected vacuum tube voltmeter, used with a matching network as an indicating source of the resonant regions of the crystal plate. See *Fig. 5.*

The frequency of the crystal is measured and the vacuum tube voltmeter readings noted. The matching network may require a degree of adjustment depending upon the frequency of the crystal being measured as well as the type of associated components used in the crystal housing. A non-inductive variable resistance is substituted for the crystal at this point and adjusted to give the same vacuum tube voltmeter

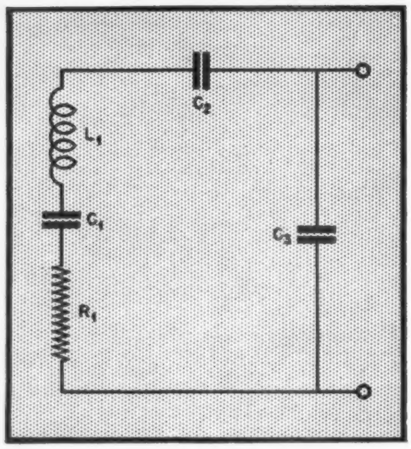


Fig. 3. Crystal equivalent network.

reading at the output of the network that existed with the crystal in the circuit. The measure of resistance obtained will be equivalent to the value $R1$ in *Fig. 3*, representing the equivalent circuit of a normally mounted quartz plate.

With the crystal replaced in the measuring circuit, a curve is now plotted of the exciting voltage value against frequency. The output voltage is maintained constant during these measurements. This measurement must be accurately plotted and preferably extend uniformly below and above the parallel and series resonance points. At this point, a known value of fixed capacity is substituted for the crystal in series with a value of resistance equal to $R1$ just measured. With this combination in the circuit the input excitation is adjusted until the output measurement of the vacuum tube voltmeter is the same value as that previously obtained with the crystal in position. From the curve obtained of input measurements versus frequency, a value of frequency is found at which the crystal reactance is equal to that of the substituted capacitor.

It is now possible to compute the equivalent circuit inductance of the crystal network. This is found from the following:

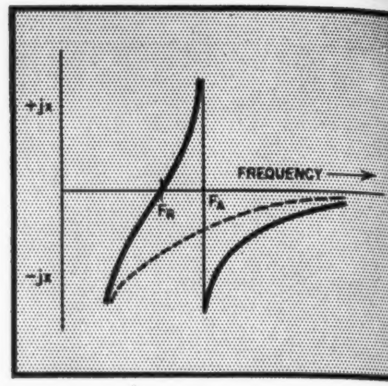


Fig. 4. Reactance of tuned circuit.

$$L = \frac{6Xc}{4\,\pi\,\Delta\,F}$$

Where Xc is the reactance of the substituted capacity at the measuring frequency, and F is the frequency increment as measured from the series resonant frequency Fr.

The crystal equivalent series capacity $C1$ is found from the formula

$$C1 = \frac{1\,Y}{(2\pi Fr)\;2L}$$

The crystal shunt capacity $C3$ in series with the airgap capacity of the electrodes of the crystal unit are shunted across the equivalent crystal network. The crystal reactance will have a value given according to the following:

$$Xc = 4\pi\,\Delta\,F\,L$$

From the foregoing brief analysis of the functioning of a quartz plate capable of exhibiting a positive reactance necessary for the control of an oscillator circuit, this set of affairs becomes most important in the high-frequency harmonic type of crystal and circuit.

Crystal "Q"

The ability of the crystal to perform this function efficiently is generally referred to as the Q of the quartz plate. This may be computed from the following:

$$Q = \frac{1}{2\pi\;Fr\;C1\;R1}$$

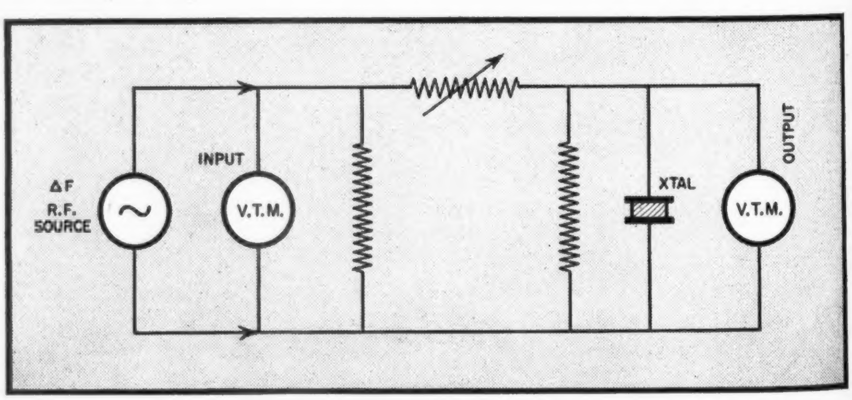


Fig. 5. Circuit for determining equivalent crystal values.

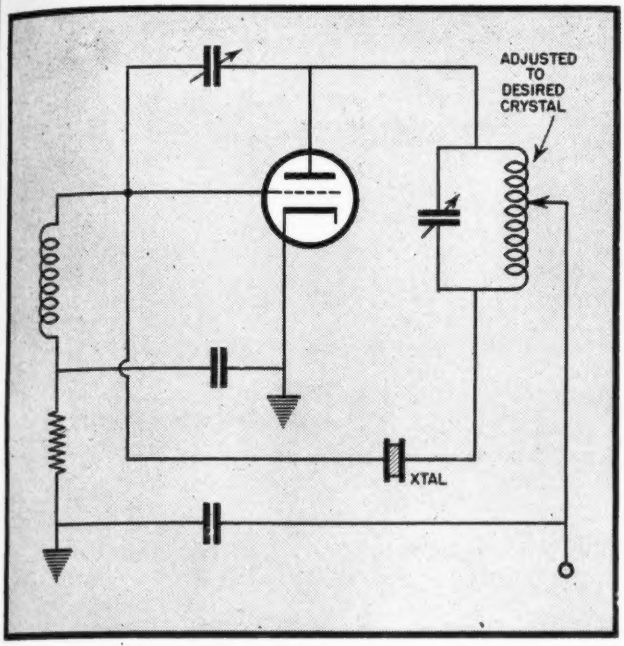


Fig. 6. Simple form of bridge oscillator circuit.

It has been shown by previous investigation (1) that it becomes increasingly difficult to excite the higher harmonic vibrations where a positive reactance of sufficient order is required to have the crystal assume control of the circuit. The limits involved may be shown as

$$\frac{P}{2} > \frac{1}{Q}$$

As explained the ratio of capacities found in the grid circuit divided by two must be greater in numerical value than the inverse quantity of the *Q*. In order to counteract the effect of the static shunt capacity *C3* across the crystal itself, which adversely affects the positive reactance desired, a different method of connecting the crystal to the oscillator circuit is resorted too. See *Fig. 6*. A balanced network with equal impedances in the various branches, calculated against the crystal with its associated reactions, is the impedance balance required to reduce the shunting effect of *C3*.

With the effect of this value of capacity removed through a static balance of the capacities of the circuit, a positive crystal reactance may be obtained by careful adjustment of the oscillator circuit. At best, the value of *C3* is always the value of the associated shunt capacity, to a larger or smaller degree, depending upon the mounting characteristics of the crystal unit. Its reactance becomes increasingly less as the order of mechanical crystal harmonic increases.

It is at once apparent that in order to be able to use, for example, the fifteenth harmonic of a six-megacycle crystal plate it is necessary that the reactance of the components associated with the crystal be of an order that will permit the crystal to provide the necessary amount of control reactance. To perform this function, a crystal must be prepared with great care in the final grinding stages. The plane parallel surfaces must conform to a symmetry and polish that is unusually perfect in view of past technique.

Fig. 5 is a simple schematic diagram of a form of high-frequency bridge oscillator circuit. Its adjustment is critical although relatively simple with an active crystal. *L1* and *C1* are designed to resonate the fundamental frequency or the odd multiple frequencies of a thickness mode oscillator crystal. The voltage tap may be adjusted to the best position of balance determined by experiment and depending upon the physical construction of the oscillator circuit. For high frequency use it is just as important to follow compact design in the oscillator stage as would be considered for amplifier stages at these frequencies.

C3, in parallel with the plate and grid interelectrode and connected capacitances, is made adjustable so that this part of the circuit may be balanced against the crystal and holder reactances removed from resonance.

With the circuit in a balanced condition, no feedback is permitted until the tuned circuit is brought near the resonant frequency of the crystal. A disturbance of the balance through the introduction of a feedback voltage is possible at the sharply resonant frequency of the crystal.

Crystal Circuit for High Harmonic Operation

In *Fig. 7* an oscillator circuit is shown, as disclosed previously,* which is capable of driving a crystal at a high harmonic of its fundamental frequency. The necessary phase shift is introduced by the inductance arrangement and the resonant circuits are tuned so that their anti-resonant frequencies coincide with the resonant harmonic of the crystal. This is the condition for maximum output and stabilization against voltage changes.

In operation, the condenser balancing the crystal is turned off its balancing value and the circuit is allowed to oscillate uncontrolled by the crystal. The grid and plate tuned circuits are next adjusted until maximum output results near the desired crystal frequency. The balancing condenser is then adjusted toward balance and the oscillation will usually stop.

[*Continued on page 68*]

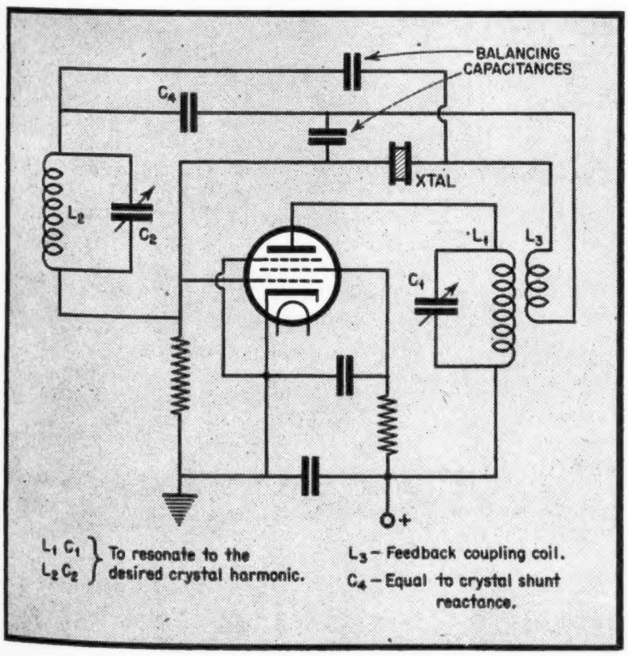


Fig. 7. Bridge circuit for high harmonic excitation. The balancing capacities and C4 are low values of capacitance; for best performance, under 5 to 10 $\mu\mu$f.

RESISTORS

Their Construction & Behavior

A. P. HOWARD

PART 2

Factors which enter into the manufacture of wire-wound resistors, and their characteristics, are described

THE wire-wound resistor possesses properties fundamentally different from the fixed-composition type previously described. Its stability, precision, and power-handling ability are easily controlled, in distinction to the composition type.

Wire-wound resistors have been subdivided into three general types for ease of description:

a.) Fixed wire-wound, power type.

b.) Fixed wire-wound, high stability, precision type.

c.) Fixed wire-wound, low operating temperature.

Each stems from a basic limitation of the composition resistor in rigorous service.

The fixed wire-wound power type, in general, contains materials inorganic in nature. For this reason, higher operating temperatures may be imposed.

A typical power resistor is the 10-watt vitreous or cement coated resistor, 1¾" long and ⅜" outside diameter. Consider, for a moment, its construction as illustrated in *Fig. 1*. The component parts of the resistor are the ceramic tube, resistance wire, terminals and coating.

A refractory tube is selected as the vehicle on which the wire is to be wound. These tubes are fairly well standardized by usage in the resistor industry and have also been standardized by the RMA, as shown in Table I. Tubes obtained from ceramic manufacturers—or in some cases made by the resistor manufacturer himself — are held to close tolerances compatible with the ceramic material.

Resistor Construction

The resistance wire selected, available from four or five sources in this country, is chosen for high resistivity, low temperature coefficient of resistance, and low iron content because of magnetic and corrosion difficulties. The wire is wound spirally on the tube with a separation between windings of ¾ of a wire diameter to a wire diameter. Brazed to the terminals embedded in the ceramic tube, the wire and core are washed with water and acid to remove oxide coatings and other impurities. Good adherence of the coating cannot be obtained otherwise.

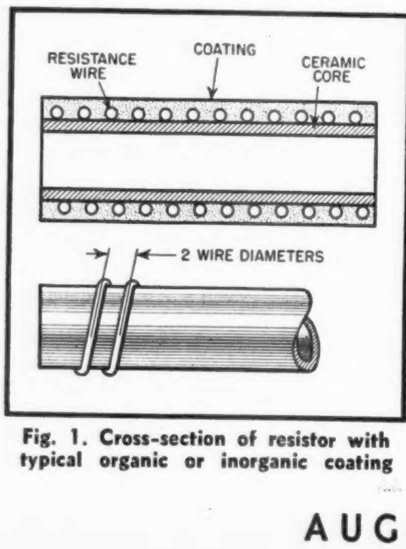


Fig. 1. Cross-section of resistor with typical organic or inorganic coating

Selection of the succeeding coatings is of importance if the resistor is to be assured a reasonable life. The factors in the selection of the coating are ambient conditions to which the resistor will be exposed, the temperature at which it will operate including the temperature rise caused by application of rated load, and the coefficient of expansion of the tube, resistance wire, and coating. It is this last factor that becomes increasingly important. To keep to a minimum the cracking of the coating with changes of temperature, the coating must be selected to match the coefficient of expansion of the wire and the tube.

The materials used in the preparation of the vitreous coating are many; among them are borax, sodium nitrate, oxides of aluminum, lead, magnesium, or tin. Color materials such as oxides of cobalt, iron, manganese, chromium, or nickel are added. The materials are selected with respect to the materials to be coated and the permissible fusing temperature. Ground, melted, poured into cold water, the material shatters into fine particles insoluble in water. From this process the basic "frit" is derived. Frit, a glass-like substance, is mixed with water and some suspension agent.

Two coatings are usually applied: a ground coating and a finished coating. The ground coat is sprayed, dipped, or dusted in dry form over the resistance element. The coat is fired at a temperature between 800°C. and 900°C. Essentially, this ground coat serves the

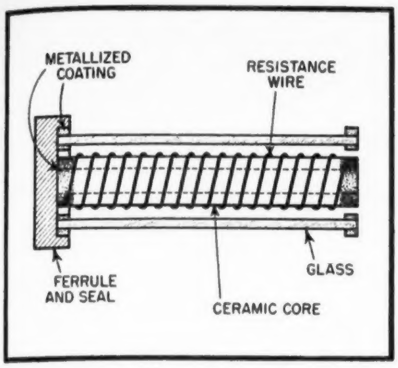


Fig. 2. Cross-sectional view of typical glass-sealed resistor

useful purpose as a prime coat to match the thermal expansion of the wire and of the outer coat.

The finished coated is usually applied wet and fired at a somewhat lower temperature.

Cement Coating

A similar coating is called a cement coating and is supplied by several manufacturers as an alternate high-temperature coating. Here the coating consists of finely-ground silicon and metallic oxide particles, held suspended in a water solution. The finished coating is applied moist and baked to final hardness instead of firing. The temperature of baking is lower than the firing temperature of the finished coat of vitreous enamel.

The baking temperature or the firing temperature is of importance in predicting the behavior of the finished resistor. Properly controlled in either case, the resistor will give satisfactory life. Two things happen in the firing which are destructive if the temperature is not properly controlled: the formation of an oxide coating on the resistance wire with an attendant change of resistance, and excessive "walking" of the wire with an attendant shorting-out of turns.

Even in normal construction, the wire walks a bit. This leads to a minimum precision to which a power-type resistor can be production-built, without special sampling. The walking is caused by the fusing of the coating under extreme temperatures and with the resistance wire momentarily free from its ceramic body and from the coating. At this time the wire moves and piles up over another bare turn, shorting out.

Several coatings in addition to those described above have been employed successfully for other applications. For excessive humidity conditions the inorganic coating (vitreous enamel or cement) has its limitations. These failures are caused by the porosity of the coating and lead to poor resistance to salt water immersion cycling and thermal shock. Two substitutes are being produced commercially which will meet the requirements of the salt-water immersion cycling.

TABLE I

RMA STANDARD RESISTOR CORE SIZES

Power Rating (Watts)	Outside Diameter (inches)	Inside Diameter (inches)	Length (inches)
10	5/16	5/32	1 3/4
20	1/2	5/16	2
25	1/2	5/16	2 1/2
40	3/4	1/2	3 1/2
50	3/4	1/2	4 1/2
80	3/4	1/2	6 1/2
100	1 1/8	3/4	6 1/2
160	1 1/8	3/4	8 1/2
200	1 1/8	3/4	10 1/2

Probably the earlier of the two was the introduction of an outer organic insulating film. Later this was applied in the form of a cement and of a paint coat. This coating did not lead to the formation of harmful oxides or to the troubles encountered in the wire walking. Because the coating was organic and form at low temperatures, often insulated wire could be employed with a reduction in space. Its limitations are the basic limitations of organic substances, for high temperature operation is not satisfactory with this resistor. The construction is essentially the same as the inorganic, illustrated in *Fig. 1.*

The second substitute was a glass-sealed ferrule-ended resistor shown in *Fig. 2.* The glass selected has a coefficient of expansion approaching that of the ferrule ends. The internal construction is the same as the other types; externally, however, the coating is not intimate with the resistance wire but serves as a sleeving.

The resistance element is placed inside the glass sleeving which has been metallized on each end. Over the glass end a low melting alloy is formed or pressed. When complete the unit is submersion-proof.

At least one manufacturer departs from single-layer winding in his construction of the glass-sealed unit. Here a progressive winding, described below, can be employed.

Rating Methods

Before discussing the limitations of each, it is necessary that we examine the commercial criterion for the rating of resistors. This method of rating has lead to derating factors, the subject of *Fig. 3.*

RMA adopted as standard in November, 1935, the following:

"M4-333—It shall be standard to rate a ceramic tube resistor with inorganic coating as that power in watts which will produce 250° C. rise at the hottest spot of a two-terminal resistor when it is suspended in air at least one foot away from the nearest object. This measurement shall be made at an ambient temperature of 40° C.

"M4-334—It shall be standard to rate a ceramic tube resistor with organic coating as that power in watts which will produce 125° C. rise at the hottest spot of a two-terminal resistor when it is suspended in air at least one foot away from the nearest object. This measurement shall be made at an ambient temperature of 40° C."

As a result of this convention, organic resistors were rated at 40% of the inorganic resistors using the same size tubes. Subsequent statements have redefined the inorganic resistor as "suitable for continuous operation at a maximum temperature of 275° C." and the organic resistor as "suitable

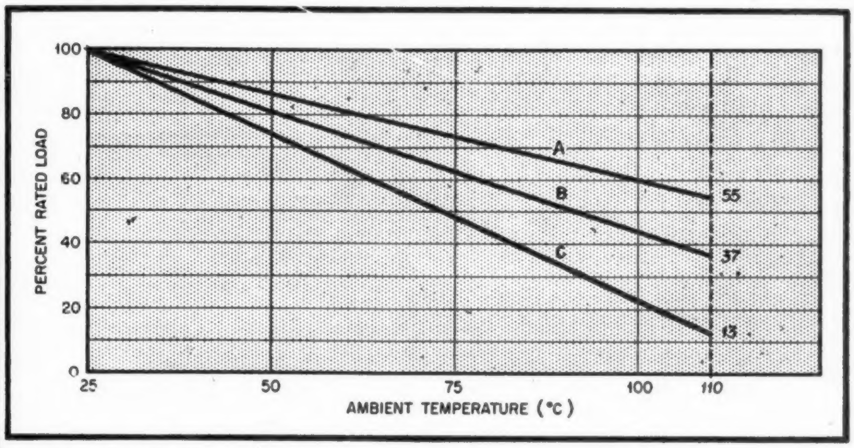


Fig. 3. Derating Cure for higher ambient temperature operation. Curve A is for resistors suitable for continuous operation C. at 275° C, max.; Curve B for 200° C. and Curve C or 125° C. Resistors.

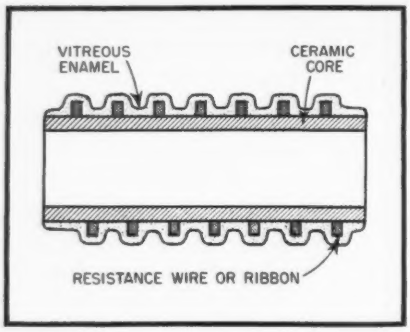


Fig. 4. Typical bare resistor construction

for continuous operation at a maximum temperature of 125° C."

Here it is assumed that measurements are conducted on random samples with a sensitive temperature-indicating device such as a thermocouple. Basically, the objection to the assumptions made by the early standardization was that additional to the standardizing on the methods of measurement, core forms were also standardized with wattage value. Every manufacturer therefore said that a 1¾" long by 5/16" ceramic o.d. by 5/32" ceramic i.d. was a 10 watt type, regardless of the true wattage rating.

In general, distinctions were made by the National Underwriters' Laboratories and NEMA among organic, inorganic, and "bare" resistors. These distinctions are carry-overs from other allied fields such as the field of wire insulation. Organic and inorganic resistors were rated in similar fashion to the RMA definitions above, but another class of bare resistor was introduced to classify those resistors with a 350°C. temperature rise.

Since the type of coating, thickness and chemical content, varied considerably, there was no true wattage rating on resistors. Some recent measurements made indicate that a manufacturer can increase his wattage one-third by proper control of the thickness of his coating.

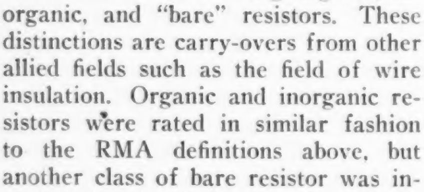


Fig. 6. Cross-Section of axial type resistor

It is these definitions that show the other failings of power resistors. Certain insulation cannot handle sufficient power in small sizes.

Wire Size

Wire size has also been a controlling factor in the type of coating selected. It is generally recognized that wire below approximately .0015" diameter is mechanically weak. Additionally small diameter wire presents problems in the firing operations increasing the spoilage.

Here again, the vitreous unit has its limitations. The Armed Forces have required therefore that .0025" diameter wire be the smallest employed on all power types used in their equipment. The decrease in wire size is not as critical in the case of the organic or cement coated, for high temperatures are not required to form the coat. Still, small wire is easily overloaded or broken. In the glass-sealed unit, the size of the wire is relatively an unimportant consideration.

The above comments however refer to the mechanical strength only required of resistance wire. Additionally, safe current densities limit the use of small diameter wire.

Several interesting variations have been introduced into power-type wire-wound resistor construction. The bare resistor, previously mentioned and illustrated in *Fig. 4,* has a thin coating of vitreous enamel over the resistance element and core. The resistance element instead of consisting of a spirally-wound resistance wire consists of twisted spirally-wound ribbon of resistance material. The ribbon is crimped continuously and then wound.

These resistors have little, if any, ability to resist corrosion of the salt-water immersion cycling type. They do, however, operate successfully at high temperatures (350°C. rise). Their primary lack is the maximum resistance obtainable under this construction. Because the resistance element consists of a ribbon instead of wire, the resistivity is considerably lower. Because the windings must be separated to give proper ventilation, the resistance winding space is low. Because the wire is exposed, the wire diameter must be increased to five sufficient mechanical strength.

In certain protected applications with low resistance but high power, the designer can save half the space.

Progressive Winding

Another interesting variation introduced recently is a progressive winding on resistors. The typical resistor is single-layer wound with a one-diameter separation and with bare resistance wire, primarily because the typical wire insulation will not withstand the high temperatures needed in manufacturing resistors. The progressive winding, shown in *Fig. 5,* is possible only because of two factors: one, a good insulation on the wire—in this case, a sintered ceramic material—and second, the design of the resistor is such that no high temperatures are necessary.

The resistance element is single or progressively layer wound of insulated resistance wire on a refractory tube. The contact to the metal leads is made by embedding the leads and the end of the resistance winding in a low melting alloy material. This prefabricated part is slipped into a glazed ceramic shell and the ends sealed with a resinous cement, melamine or phenolic.

This progressive winding leads to higher resistance values than are usually obtained in the conventional styles. The wattage is limited to a 200°C. rise due to the organic ends

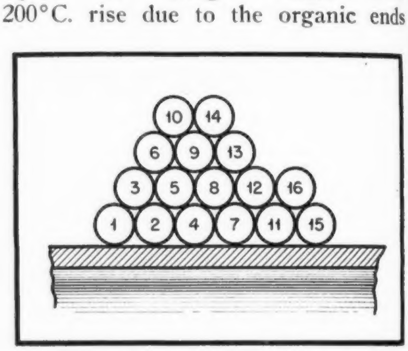


Fig. 5. Progressive winding which tends to reduce voltage gradients

and because of the low melting alloy tips. The construction, shown in *Fig. 6,* is radically different from the types in general use. The limitations of this resistor appear to be its somewhat lower operating temperature the possibility of steep wave fronts or other surges breaking down the wire insulation by causing a momentary overload, and the effectiveness of the sealed ends. Types recently tested show that the resin employed for sealing the ends is capable of exposure to a wide range of temperatures and moisture conditions without any noticeable damage.

As a means of summarizing the types described, the author wishes to list the advantages and disadvantages of the types surveyed:

Inorganic coating (vitreous enamel or cement) . . . medium resistance range, high power handling ability, limited ability to meet salt-water immersion.

Organic coating . . . extended resistance range with small diameter wire or insulated wire and non-space wound, lowest power handling ability, high ability to meet salt-water immersion.

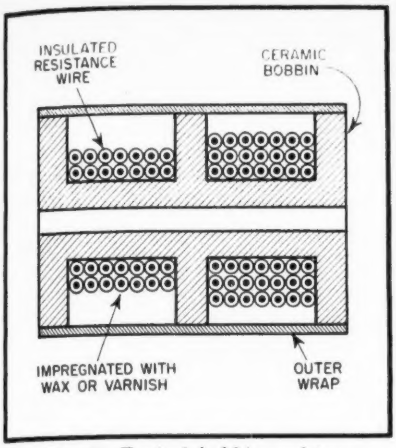


Fig. 7. Typical bobbin resistor

Glass-sealed coating . . . medium resistance range which can be increased with progressive winding, high power handling ability, high ability to meet salt-water immersion, large in size.

Bare resistor . . . low resistance range, highest power handling ability, not satisfactory under salt-water immersion or extended high humidity.

Progressively-wound axial type . . . high resistance range, medium power handling ability, not satisfactory under salt-water immersion but satisfactory under extended high humidity.

Consider this another way:

Watts/cubic inch	*Ohms/cubic inch*
1. Bare resistor	1. Axial type
2. Inorganic coating	2. Organic coating
3. Glass-sealed	3. Inorganic coating
4. Axial type	4. Glass-sealed
5. Organic coating	5. Bare resistor

Precision Resistors

The precision resistor poses some additional problems which are not akin to the power resistor. The construction of several types of precision resistors, shown in *Figs. 7* and *8*, will point out the differences to be encountered.

A precision resistor, without regard for its construction, is fundamentally a fragile piece of equipment. It is wound to an accuracy commercially of 0.1% or better and is built to handle small power requirements with high resistance values to 10 megohms or more.

The resistance wire is carefully selected to be of constant diameter and resistivity. It is commonly hand wound to insure its precision. After the completed winding is assembled, the units are usually coated or covered for humidity protection.

The more common precision resistor is the bobbin style illustrated in *Fig. 7*. Here an even number of sections are filled with resistance wire. The direction of winding is reversed every pie (section) to create a non-inductive effect. Non-inductive qualities of wire-wound units will be discussed later.

The second construction, *Fig. 8*, employs a ceramic or paper tube for the coil form and interlaces the resistance layers with insulating paper. The direction of winding is changed frequently to create a non-inductive effect. This resistor gives better dielectric protection, but is effectively larger.

Several types of coating are employed including the usual impregnating varnishes and waxes. Several covers have been used, including a glass tube and a cellulose acetate wrap.

Upper limit on the wattage is about 120°C. ambient (hot spot) temperature. The wire insulation employed and the impregnating compounds prohibit the resistor's use above that point.

Types of Wire Used

Three types of wire are used in precision resistors: Nichrome or equivalent with high resistivity and highest (of the three) temperature coefficient of resistance; constantan with a medium resistivity, high thermal e.m.f. against copper, and lowest temperature coefficient of resistivity; and manganin, with the same properties relatively as constantan, but a low thermal e.m.f. against copper.

The weaknesses of precision resistors as now prepared can be traced to the tendency on the part of some manufacturers to pack as much resistance as possible onto the smallest possible spool. This can be done only by decreasing the wire diameter. Some units have been built with wire diameters approaching .0007". To say that this leads to instability is understating the case. With the use of small diameter wire, the resistance increases as the square of the ratio of the wire diameters, but the loss of mechanical strength and the decrease of dielectric strength increases at a more alarming rate.

The end result of employing smaller diameter wires is a precision resistor with limited life. With the decrease in insulation thickness, the dielectric protection diminishes; with the decrease in metal sizes, winding stresses are more readily set up but less readily removed by the usual ageing processes; decreasing the wire size gives corrosion more chance to set in.

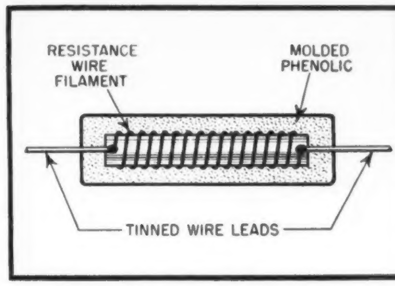


Fig. 9. Low temperature operating wire-wound resistor

The Armed Forces are insisting on a wire size not smaller than 1.5-mil diameter in their proposed specification on resistors. These specifications are not final as yet—but 1.5-mil diameter is just on the borderline unless further protection is given the finished component. Such provisions are in the specification, also.

In general, these resistors are no match for salt-water immersion cycling. Attempts have been made with success to improve the humidity characteristics of the components.

The third type of resistor is the wire-wound resistor, low operating temperature, illustrated in *Fig. 9*. Maximum operating temperature of this type is approximately 100°C., a limitation imposed by its bakelite shell.

The resistance elements consists of spirally wound wire on a fabric or glass form. This element is moulded into bakelite similar to the composition type, previously discussed.

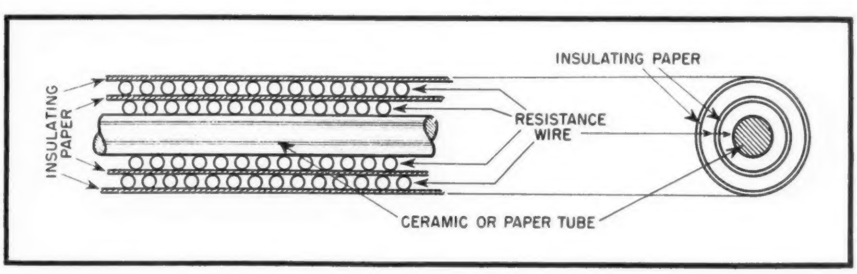
These resistors were introduced because the control of a carbon element is difficult in the lower resistance values and because of the instability of the carbon type in general. It is indeed unfortunate that the maximum resistance obtainable is approximately 5000 ohms, for in low noise high stability circuit their use would be desirable.

Non-Inductive Windings

There are several types of non-inductive construction commercially available to the resistor purchaser, wound by the following methods:

[*Continued on page 66*]

Fig. 8. Layer wound precision resistor



L PAD as an Impedance Matching Device in POWER TRANSFER NETWORKS

WILLIAM VISSERS, JR.
Massachusetts Institute of Technology

The L pad is a simple and efficient means of matching impedances. General equations for all types of impedances are given.

A PROBLEM that often confronts the engineer is that of designing a network to match one impedance against another for maximum power transfer. A pi or T network has the advantage of allowing the phase shift between input and output voltages to be predetermined as a part of design calculations, but an L section while not allowing any precalculated phase-shift determination, has the advantage of using only two rather than three components, and of being more efficient for a given transformation ratio, assuming the "Q" of all relative components to be the same. Numerous texts give the equations needed to solve for such a network when the impedances to be matched are both resistive, but in many design problems there is a definite need for general equations that cover all types of impedances encountered.

Avoiding Losses

To avoid losses the resistive components of the shunt and series arms in the pads must be kept as low as possible, and following conventional network design, the elements can be considered to be pure reactances.

Fig. 1 shows a generator with impedance Z_1 feeding a load of impedance Z_2. For maximum power transfer the impedance of the load must be the conjugate impedance of the generator, i. e., if Z_1 is $R_1 + jX_1$, then Z_2 must equal $R_1 - jX_1$.

The function of the matching network is to present the generator with its conjugate load at *AA (Fig. 2A)*, when Z_2 is connected, and present the load Z_2 with its conjugate impedance at *BB (Fig. 2B)* when Z_1 is connected.

Since both Z_3 and Z_4 are pure reactances, there is no dissipation in the network, and all of the power absorbed at the input terminals is transferred to Z_2. Any change in the value of Z_3 and/or Z_4 would change the value of impedance at *AA* from its Z_1 conjugate value and decrease the power delivered to Z_2. Hence, if a conjugate

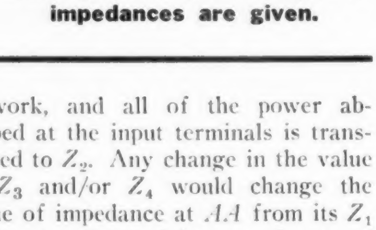


Fig. 1. Generator with impedance Z_1 feeding load of impedance equal to Z_2

match is obtained at *AA (Fig. 2A)*, a conjugate match is necessarily obtained at *BB*.

It is possible to write the following equation for *Fig. 2A:*

$$R_1 - jX_1 = \frac{(jX_3)(R_2 + jX_2 + jX_3)}{R_2 + j(X_2 + X_3 + X_4)} \quad \ldots (1)$$

Cross-multiplying and separating the real components from the imaginary components gives equation (2), while taking advantage of the fact that the sum of the reals and the sum of the imaginaries both equal zero gives equations (3) and (4).

$$R_1R_2 + X_1X_2 + X_1X_3 + X_1X_4 + X_2X_3 + X_3X_4 + j(R_1X_2 + R_1X_3 + R_1X_4 - X_1R_2 - R_2X_3) = 0 \quad \ldots (2)$$

$$R_1R_2 + X_1X_2 + X_1X_3 + X_1X_4 + X_2X_3 + X_3X_4 = 0 \quad \ldots (3)$$

$$j(R_1X_2 + R_1X_3 + R_1X_4 - X_1R_2 - R_2X_3) = 0 \quad \ldots (4)$$

Multiplying both sides of equation (4) by $-j$ gives equation (5), and it is now seen that equations (3) and (5) are two separate equations containing the two unknowns X_3 *and* X_4.

Reactance Values

Straightforward algebraic manipulation and the use of the quadratic equation for solution give two sets of values for X_3 *and* X_4 as shown in equations (6) and (7).

$$R_1X_2 + R_1X_3 + R_1X_4 - X_1R_2 - R_2X_3 = 0 \quad \ldots (5)$$

$$X_3 = \frac{R_2X_1 + \sqrt{R_1R_2X_1^2 + R_1^3R_2 - R_1^2R_2^2}}{R_1 - R_2} \quad \ldots (6A)$$

$$X_4 = -\frac{R_1X_2 + \sqrt{R_1R_2X_1^2 + R_1^3R_2 - R_1^2R_2^2}}{R_1} \quad \ldots (6B)$$

$$X_3 = \frac{R_2X_1 - \sqrt{R_1R_2X_1^2 + R_1^3R_2 - R_1^2R_2^2}}{R_1 - R_2} \quad \ldots (7A)$$

$$X_4 = -\frac{R_1X_2 - \sqrt{R_1R_2X_1^2 + R_1^3R_2 - R_1^2R_2^2}}{R_1} \quad \ldots (7B)$$

If it happens that the values of Z_1 and Z_2 are such that the expression

[*Continued on page 62*]

ACCELERATION CHART

ENGINEERING DEPARTMENT
Sylvania Electric Products, Inc.

The now common use of electronic apparatus in planes, tanks, and battleships has made design engineers conscious of problems due to vibrations and high accelerations. Most vibrations encountered in service are not simple harmonic motion, but standards have been set up based on vibrations of this nature which are satisfactory for comparison purposes. Similarly, the high accelerations found in service may not be uniform but here again a readily reproducible standard is used for test and comparison.

The forces due to vibrational or accelerated motion are commonly expressed as the number of times these forces exceed that of gravity which is used as the unit. Thus, when $G = 1$, the force is equal to that of gravity. The equation is $G = 0.10225 f^2 r$ in which

G = ft. per sec. per sec. = 32.176 ft./sec.^{2}
f = frequency in cycles per sec.
r = amplitude of vibration in inches.

Amplitude of vibration (r) is the distance traveled each side of the rest point and should not be confused with the total distance travelled.

For Vibratory Motion

The attached chart is reasonably accurate and much quicker than calculating from the equation. To use it, lay a straight edge across the chart connecting two of the known values. The unknown will be found at the intersection with the third line. For example, a ruler joining the point on the first line corresponding to 0.04″ amplitude with the point on the third line for 10G will intersect the center line of the chart at 49 cycles which is the frequency required to produce approximately 10G acceleration with 0.04″ amplitude. This is the peak value impressed on the test object, twice in each cycle and in opposite directions.

For Rotary Motion

The chart is used similarly to obtain the acceleration due to the centrifugal force on a rotating object as in a centrifuge. In this case the radius takes the place of the amplitude and revolutions per second takes the place of vibrations per second.

It should be pointed out that the two methods are for entirely different purposes. The vibration method tests the structure's ability to withstand stresses in alternate directions, thus measuring resistance to fatigue in the flexed parts and resistance ot wear at contact surfaces. The centrifugal force method measures the ability of a structure to withstand acceleration in one direction only and applied constantly.

BOOK REVIEW

RADIO DIRECTION FINDERS by Donald S. Bond. Published (1944) by McGraw-Hill Book Company, 330 W. 42nd Street, New York 18, New York. 274 pages. Price $3.00.

Radio direction finding had its origin almost as early as radio communication, but the progress for the first few years in this field was relatively small. However, in the past ten years, progress in the field has been so rapid that only a specialist has been able to keep abreast of the literature and of the development. Despite its long history, the subject of radio direction finders has been treated extensively by only one other English author, R. Keen, "Wireless Direction Finding." Mr. Bond's book is a compendium of theoretical and practical information underlying the art. It treats particularly fully the more conventional types of direction finding equipment. The author has adopted much of the worth while mathematical theory from the literature.

The book is divided into seven chapters and an appendix as follows:

1. General Considerations
2. Wave Propagation
3. Directive Antenna Systems
4. Aural Null Direction Finders
5. Performance Characteristic of Loop Input Circuits
6. Visual Direction Finders
7. Radio Navigation Aids

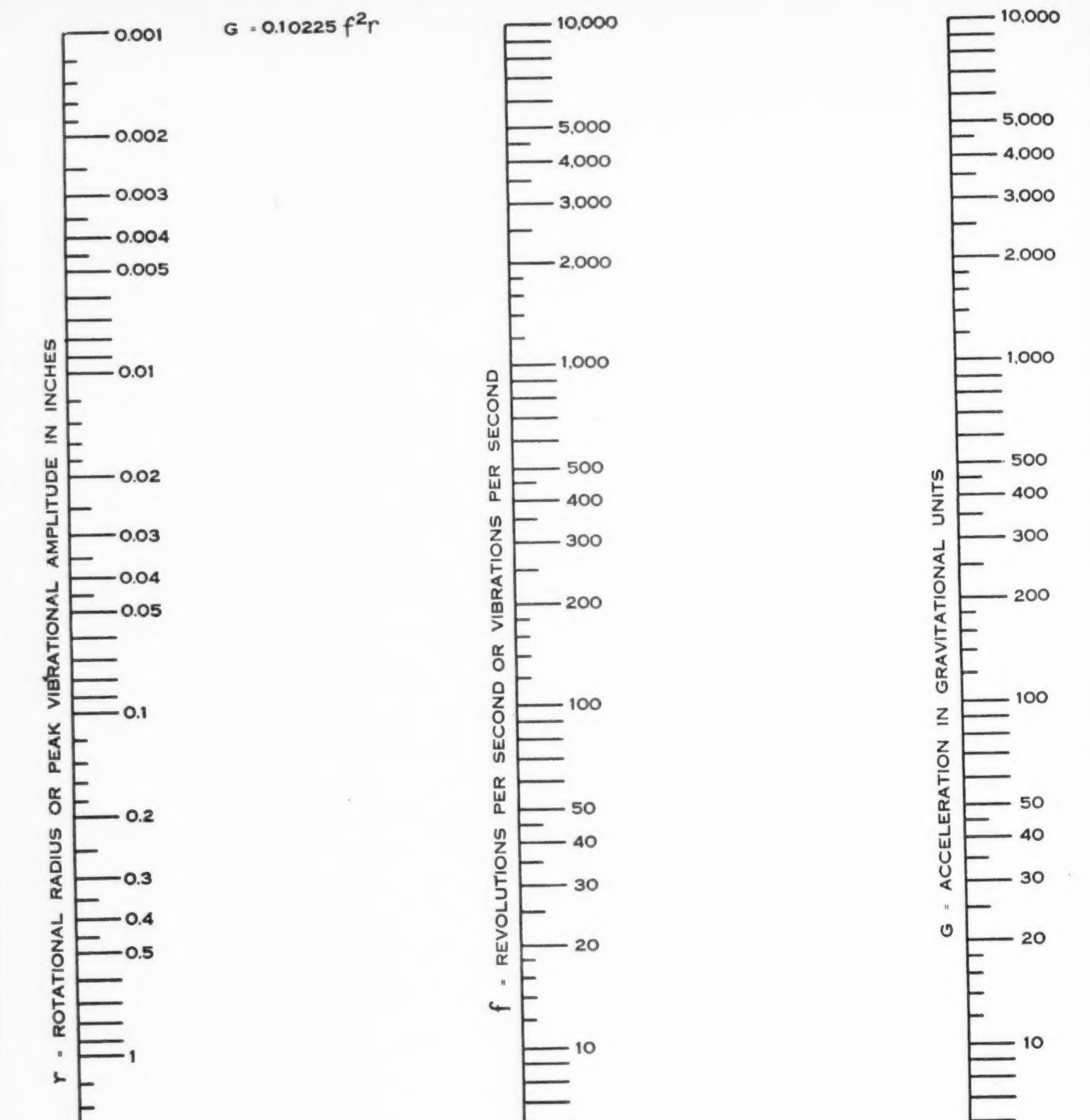
The first section treats direction finders as specialized radio receivers. The methods of testing by RTCA and IRE are discussed in some detail. Included in this chapter is a six page chart of tests and notes relating to direction finder equipments. The second section consists of a summary of the literature of the past several years on wave propagation. The contents of this section are devoted chiefly to range computations for idealized earth surface conditions.

The section on Antennas is especially noteworthy in that it treats rather fully the three important types of direction finder antenna; notably, Adcock, Spaced-loop, and the simple loop. Errors due to oblique polarization receive special attention; comparisons being drawn between the various types of direction finding antennae. The section on Aural Null Direction Finders lays special emphasis on phase relation in Resonant RF Circuits. Phase is important in Direction Finders, particularly when signals from directive and non-directive antennae are combined to obtain a sense indication. This section deals not only with the theoretical aspects of phase, but also errors due to adjacent objects, or terrain as well as compensation and calculation of deviation error with and without balancers.

Some sixty pages are devoted to Visual Direction Finders. Visual Direction Finders have become extremely important in the years immediatly preceding the war for the navigation of aircraft. Obviously, aircraft traveling at the rate of several miles per minute may require many position readings in a short space of time. Visual Direction Finders either singly or in combination offer an admirable solution to this problem. In this section is discussed particularly RCA, Sperry, and Bendix Direction Finders.

The appendix, which deals with radiation from a Dipole, Field Strength Calculations for Propagation over a Plane Earth, and Phase Relations in Coupled Circuits is especially noteworthy and of considerable importance to most readers.

This book, being the only one published on the subject in English since Keen's work on "Wireless Direction Finding," fills a need which has been felt for a number of years. A great deal of work has been done on electronic navigation equipment since Keen's book was written, and this text serves to bring the reader up to date. It is recommended both to the practical and theoretical worker in this field, as well as to engineers generally interested in the subject. In addition, it should serve as an excellent reference book for specialists in the field.


G = 0.10225 f²r
r - ROTATIONAL RADIUS OR PEAK VIBRATIONAL AMPLITUDE IN INCHES
0.001
0.002
0.003
0.004
0.005
0.01
0.02
0.03
0.04
0.05
0.1
0.2
0.3
0.4
0.5
1
2
3
4
5
10
f - REVOLUTIONS PER SECOND OR VIBRATIONS PER SECOND
10,000
5,000
4,000
3,000
2,000
1,000
500
400
300
200
100
50
40
30
20
10
5
4
3
2
1
G - ACCELERATION IN GRAVITATIONAL UNITS
10,000
5,000
4,000
3,000
2,000
1,000
500
400
300
200
100
50
40
30
20
10
5
4
3
2
1

RADIO DESIGN WORKSHEET

NO. 28

SIDEBAND POWER OF AN AMPLITUDE-MODULATED WAVE; METHODS OF FREQUENCY MODULATION; MUTUAL INDUCTANCE FILTERS

SIDEBAND POWER OF AN AMPLITUDE-MODULATED WAVE

The general expression for an amplitude modulated wave is

$$I = A \cos \omega t \ (1 + K \cos pt)$$
$$= A \cos \omega t \frac{AK}{2} \cos (\omega + p) t$$
$$+ \frac{AK}{2} \cos (\omega - p) t$$

where

$\omega = 2\pi \times$ carrier frequency
$p = 2 \times$ modulating frequency
$K =$ percentage modulation

If the carrier is completely modulated, $K = 1$.

From the above expression the amplitude of each sideband is one-half the carrier amplitude for complete modulation.

The root-mean-square current is

$$I = \sqrt{A^2 + \frac{A^2}{4} + \frac{A^2}{4}}$$
$$= \sqrt{\frac{3}{2} A^2}$$

Power is proportional to

$$I^2 = \frac{3}{2} A^2$$

Power of the unmodulated carrier is proportional to A^2. Thus, the ratio of power in the modulated carrier to that in the unmodulated carrier is

$$\frac{1.5A^2}{A^2} = \frac{1.5}{1} = 1.5$$

whence the peak power capability of the transmitter must be 50% greater than the rated carrier power. The two sidebands obviously carry one-third the radiated power.

The ratio of antenna current for carrier modulated completely to the unmodulated carrier is obviously $\sqrt{1.5} = 1.225$, so the antenna current increases 22.5% for complete modulation.

From the above it follows that two-thirds of the radiated power of a completely modulated wave does not bear intelligence. If the carrier and one sideband were suppressed and only one sideband were radiated, all the radiated power would bear intelligence. Such a transmitter would therefore radiate four times as powerful a signal with a single sideband instead of a carrier and two sidebands, assuming the same transmitter power capability. Single sideband transmission with and without carrier suppression has been widely used in wire telephony and to a limited extent in fixed point-to-point radio telephone installations.

Practical methods of carrier suppression and of isolating one sideband will be discussed in future worksheets.

METHODS OF FREQUENCY MODULATION

Fig. 1 shows a resistance in parallel with a reactance which may be used to vary the resonant frequency of an oscillator tuned circuit thus achieving frequency modulation. First consider the circuit of *Fig. 1* in which the resistance r may be a carbon microphone on the plate impedance of a vacuum tube. Either may be made to vary in magnitude in accordance with a modulating frequency.

$$Z = \frac{r \times jx}{r + jx} = \frac{jrx}{r + jx}$$

Multiplying by:

$$\frac{r - jx}{r - jx}$$

we have:

$$\frac{rx^2 + jr^2x}{r^2 + x^2} = Z$$

Since

$$j = \sqrt{-1},\ j^2 = -1 \text{ and } -j^2 = +1$$

Thus:

$$Z = rx^2 + j\frac{r^2x}{r^2 + x^2} = A + jB$$

Where:

$$A = \frac{rx^2}{r^2 + x^2} \text{ and } B = \frac{r^2x}{(r^2 + x^2)^2}$$

$$\frac{\delta A}{\delta x} = \frac{2rx(r^2 + x^2)}{(r^2 + x^2)^2} - 2rx^3 = \frac{2r^3x}{(r^2 + x^2)^2}$$

When $r = x$

$$\delta A/\delta x = 2r^4/(2r^2)^2 = 2x^4/(2x^2)^2 = 1/2$$

$$\delta B/\delta x = \frac{2r^2(r^2 + x^2) - 2r^2x^2}{(r^2 + x^2)^2} = \frac{r^2(r^2 - x^2)}{(r^2 + x^2)^2}$$

$$\delta B/\delta x = r^2(r^2 - r^2)/(r^2 + r^2)^2 = 0$$

This determines the general shape of the curve of A' as a function of r. *Fig. 2* shows the general shape of this expression.

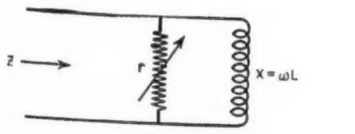


Figure 1

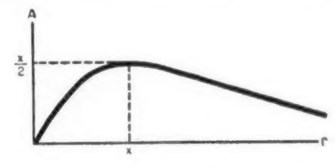


Figure 2

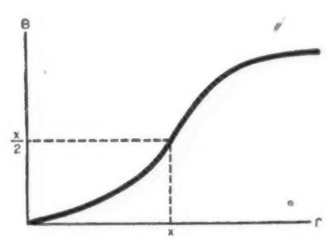


Figure 3

RADIO DESIGN WORKSHEET . . . NO. 28

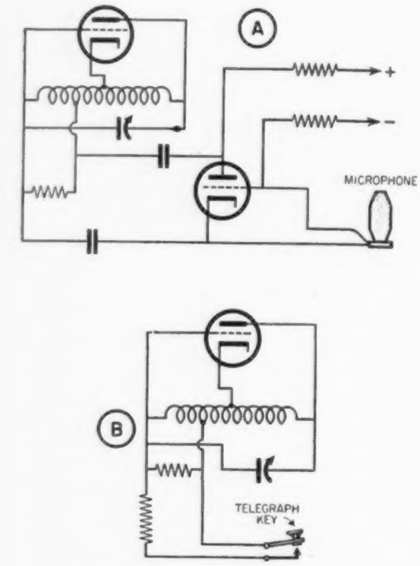


Fig. 4. F-M Circuits

Thus if: $r = x$, $A = x^3/2x^2 = x/2$
if: $r = 2x$, $A = 2x^3/5x^2 = 2x/5 = 0.4x$
if: $r = 0.5x$, $A = 0.5x^3/1.25x^2 = 0.5x/1.25 = 0.2x$
Now, $B = r^2x/r^2+x^2$
if: $r = x$, $B = x/2$
if: $r = 2x$, $B = 4x^3/4x^2 + x^2 = 4/5x = 0.8x$
if: $r = 0$, $B = 0$

This determines the general configuration of the curve of B as a function of r, which is shown in *Fig. 3*.

From the above it is evident that variations of r about the point $r = x$ result in a maximum change in B, the imaginary component of Z.

Consequently, if the circuit of *Fig. 1* is incorporated in the tuned circuit of an oscillator as shown in *Fig. 4*, and r is varied, the resonance of the circuit and consequently the frequency of the oscillator is changed in accordance with the above formulae. If a normal value of $r = x$ is chosen, then the damping of the circuit will remain essentially constant and the amplitude of oscillation will be little affected over a small range. This results in frequency modulation without appreciable amplitude modulation. A limiter following the oscillator in the circuit could remove the amplitude modulation quite readily, of course.

The reactance X in the above formulae may be either inductive, as shown, or capacitive. That is, $x = \frac{1}{\omega C}$ or $x = \omega l$. This method of modulation can be applied either to self-excited or crystal oscillators. In spite of its simplicity, this method of modulation is relatively unimportant and has found little use to date. In future worksheets, other methods of frequency modulation will be described and then relative advantages and disadvantages will be indicated as compared with this method.

MUTUAL INDUCTANCE FILTERS

In Radio Design Worksheet No. 20,* the mutual inductance bridge was discussed. A bridge can be considered as a lattice network, which is a common type of filter circuit, see *Fig. 5*.

An interesting variant of the mutual inductance bridge, known as the Campbell balance, is sometimes used in filter circuits. Thus if two inductances are placed in such position that there is magnetic coupling between them, an increase or decrease in the total inductance of the combination results, due to the mutual inductance. This is illustrated in *Fig. 6*. The total series inductance of the circuit of *Fig. 6* is:

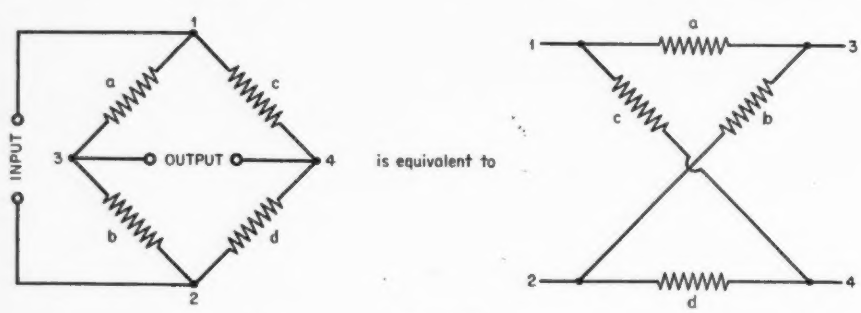


Figure 5

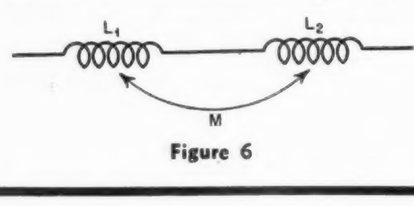


Figure 6

$$L_1 + L_2 \pm 2M$$

where M may be positive or negative, finite or zero. *Fig. 6* may be represented as shown in the T network of *Fig. 7*.

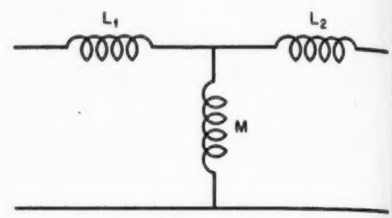


Figure 7

The Campbell balance utilizes the fact that M may be resonated with a capacitor C, as shown in *Fig. 8*. When C and M are in resonance, the loss at resonant frequency is infinite, assuming neither M nor C has any dissipation or resistance. In actual practice the loss is finite, but can be made very high. This is sometimes used to increase the loss of a filter at a specific frequency. Thus, at resonance

$$2\pi fM = 1/2\pi fc$$
$$C = 1/4\pi^2f^2M$$

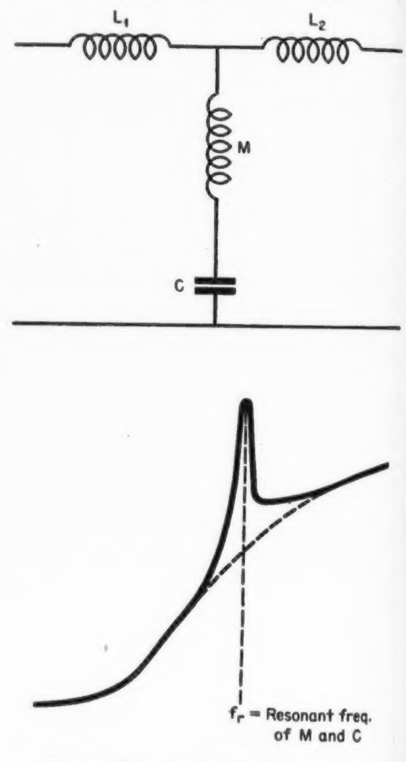


Figure 8. Campbell balance circuit and resonance curve

* RADIO, Dec., 1943.

This Month

ELECTRONICS CONFERENCE

A comprehensive program covering television, ultra-high frequency and radio developments in the communications field and industrial measurements, electronic controls, induction heating, and power and medical applications of electronics is announced by the Executive Committee of the National Electronics Conference to be held at the Medinah Club, Chicago, Oct. 5-7.

Dr. J. E. Hobson, Director of the School of Engineering of the Illinois Institute of Technology is chairman of the Executive Committee of N. E. C. According to a statement made by him recently, "The first National Electronics Conference is planned to provide: (1) a technical meeting for the presentation of original papers covering fundamental developments in electronics and the applications of electronic apparatus, (2) a forum for the review and correlation of recent electronic developments in their proper perspective, (3) a symposium for the interchange of ideas, methods of approach and technique between scientists and electronic engineers working in different fields of application, and (4) an educational conference to acquaint engineers with this relatively new and rapidly expanding field.

"In addition to providing a permanent record of technical and application papers for reference and study," Dr. Hobson continues, "the Conference should serve to help integrate and correlate work being done in fields rather divergent in their applications of electronic devices and principles. Although including the use of electronics in communications, the first Conference will emphasize scientific developments and also applications in industry, processing operations, power conversion, measurements, medicine and similar important fields.

"Keynoter speakers for the technical sessions will give broad perspectives of progress in the various fields, and expectations for future developments. Opportunity will be given throughout the Conference for conference-type discussions."

Comprehensive Program

A comprehensive program, embracing all important fields of electronics has been prepared by Prof. Arthur B. Bronwell, Northwestern University, Evanston, Ill., who is also Chairman of the Program Committee. Outstanding engineers and scientists have promised to prepare technical papers for presentation at the Conference. Although the program is still subject to some minor modifications and changes, the tentative program indicates that practically all persons interested in one or more branches of the broad field of electronics will find a program suited to their interests.

Keynoting the objectives of the Conference will be an opening address by Mr. Ralph R. Beal, entitled, "Electronic Research Opens New Frontiers." Mr. Beal's position as Research Director for the Radio Corporation of America provides adequate guarantee that a broad perspective of the present status of the electronics industry will be given, as well as a thought-provoking analysis of probable future developments.

Perry Smith of RCA operating an RCA Electron Microscope

Looking to industry as well as to research for future developments in electronics, the Conference is assured that Mr. W. C. White, Director of the Electronics Laboratory, General Electric Co., will speak on "Electronics in Industry" at one of the Conference luncheons.

The tentative program of technical topics for the Conference includes the following papers grouped according to main topic divisions:

(1) *Television*

"Color and Ultra-High Frequency Television" by *Dr. P. C. Goldmark,* Columbia Broadcasting System.

"Reflection Optics in Television" by *I. G. Maloff* and *D. W. Epstein,* RCA Manufacturing Co.

"Radio Relay Systems" by *C. W. Hansell,* RCA Laboratories.

(2) *Ultra-High Frequencies*

"A Lighthouse Tube; a Pioneer U.H.F. Development" by *E. F. Peterson* and *E. D. McArthur,* General Electric Co.

"Principles of Klystron Amplifiers" by *Dr. Robert Haxby,* Sperry Gyroscope Co.

"Developments of Electronic Tubes" by *I. E. Mourontseff,* Westinghouse Electric and Manufacturing Co.

"Wire-Frequency-Range Tuned Circuits for High Frequencies" by *Dr. D. B. Sinclair,* General Radio Co.

"Ultra-High Frequency Converters and Conversion Diagrams" by *Dr. Harry Stockman,* Cruft Laboratory, Harvard University.

(3) *Radio*

"A Method for the Generation of Quasi-Continuous Frequency Spectra for Use with Secondary Frequency Standards" by *Dr. Harold Goldberg* and *Richard G. Talpey,* Stromberg-Carlson Telephone Manufacturing Co.

"A Frequency Dividing Lock-In Oscillator F-M Receiver" by *G. L. Beers,* RCA Manufacturing Co.

"Incremental Permeability Tuning," by *W. J. Polydoroff,* Consulting Engineer

"Audible Audio Distortion" by *H. H. Scott,* General Radio Co.

[*Continued on next page*]

This Month

"Broadband Carrier and Coaxial Cable Networks" by *F. A. Cowan,* American Telephone and Telegraph Co.

(4) *Industrial Measurements and Special Devices*

"The Supersonic Reflectoscope; An Instrument for Inspecting the Interior of Metal Parts by Means of Sound Waves" by *Dr. F. A. Firestone,* University of Michigan.

"Dynamic Strain Gages" by *C. A. Dohrenwend,* Armour Research Foundation.

"The Mass Spectrometer and Its Practical Applications" by *J. A. Hipple,* Research Laboratories, Westinghouse Electric and Manufacturing Co.

"Two-Million Volt X-Ray Unit" by *Dr. E. E. Charlton* and *W. F. Westendorp,* General Electric Co.

"Industrial Fluoroscopy of Light Materials" by *Dr. Scott W. Smith,* Kelley-Koett Manufacturing Co.

"Application of Amplifier Theory to Mechanical Stability Problems" by *John M. Cage,* Allis-Chalmers Mfg. Co.

(5) *Industrial Electronic Controls*

"Electronic Mechanisms in Process Plant and Industrial Laboratory" by *T. A. Cohen,* Wheelco Instrument Co.

"Electronic Measurements of Non-Electrical Quantities in Industrial Processes" by *H. D. Middell,* General Electric Co.

"Cathode Ray Tubes and Their Application" by *Dr. P. S. Christaldi,* Allen B. DuMont Laboratories. "Electronics in Industrial Instrumentation" by *Walter P. Wills,* Brown Instrument Co.

"Design Factors in the Application of Relays to Electronic Circuits" by *R. H. Herrick,* Automatic Electric Co.

(6) *Induction Heating*

"High Frequency Induction Heating by *C. J. Madsen* and *R. M. Baker,* Westinghouse Electric and Manufacturing Co.

New RCA electronic pre-heater for plastics. At the end of a pre-determined heating interval, the lid automatically pops up

"New Methods and Techniques in High Frequency Heating" by *Dr. Eugene Mittelmann,* Illinois Tool Works.

"The Use of High Frequency Electronic Generators to Obtain Controlled Power Concentrations for Industrial Heating Applications" by *Dr. Wesley Roberds,* RCA Manufacturing Co.

(7) *Electronic Applications in the Power Field*

"A Survey of Power Applications of Electronics" by *A. C. Montieth,* Westinghouse Electric and Manufacturing Co.

"Power Rectifiers and Inverters" by *J. A. Cox* and *G. F. Jones.* Westinghouse Electric and Manufacturing Co.

"Electronic Power Converters" by *Dr. E. F. W. Alexanderson,* General Electric Co.

(8) *Medical Applications of Electronics*

"Electronic Equipment in the Medical Profession" by *Dr. A. H. Carter,* American Medical Association.

"Electroencephelography" by *Dr. Ralph Girard,* University of Chicago.

(9) *Recent Theoretical Developments in Electronics*

"Theory of Microwave Oscillation Generators Using Velocity Modulated Electron Beams" by *Dr. E. U. Condon,* Westinghouse Electric and Manufacturing Co.

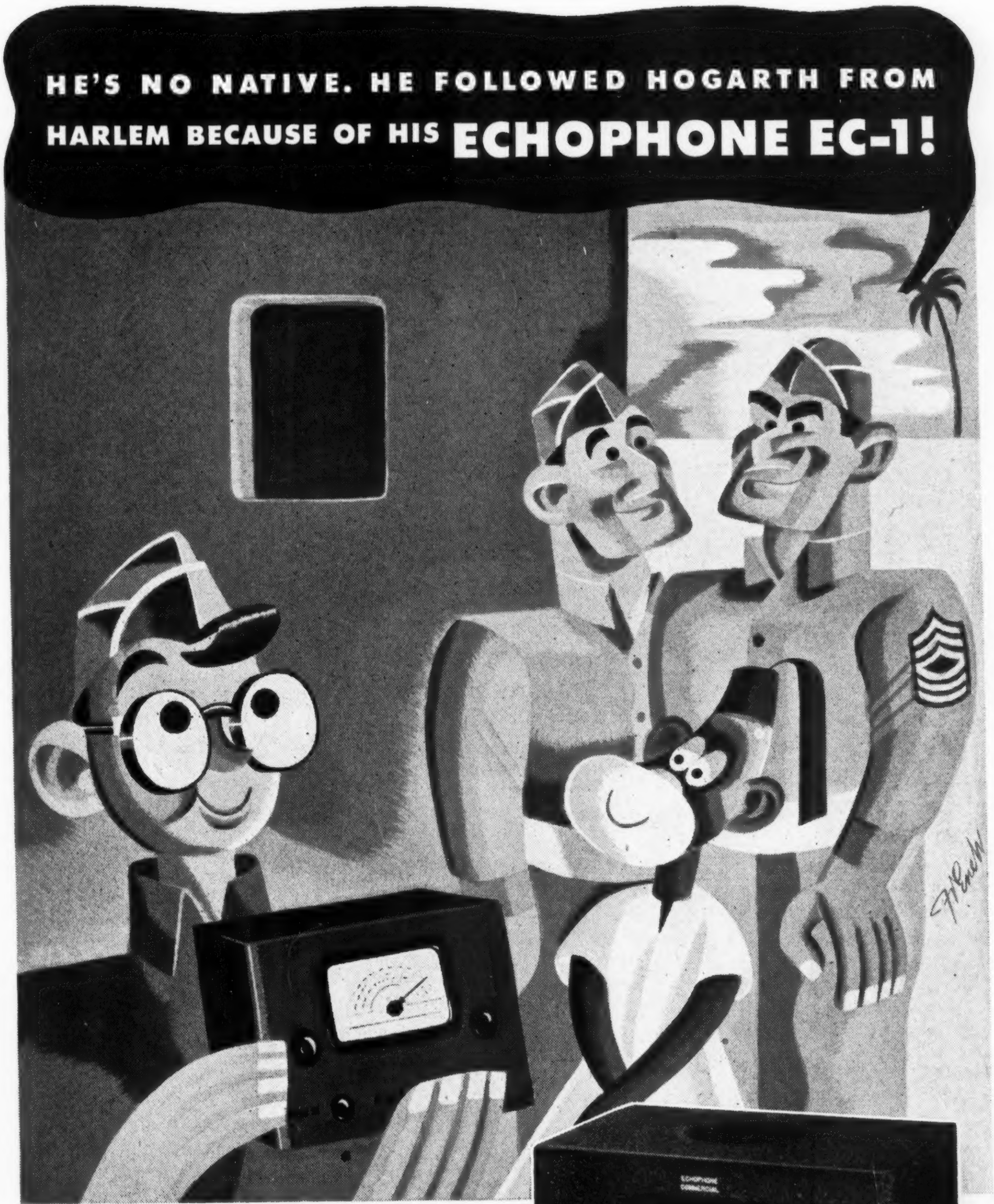
"Theorem of Lorentz and Its Importance for all Problems of Electrons in Magnetic Fields" by *Dr. Leon Brillouin,* Columbia University.

"Transient Response of Wide-Band Amplifiers" by *Dr. W. W. Hansen,* Sperry Gyroscope Co.

The Medinah Club of Chicago, 505 N. Michigan Ave., Chicago 11, Ill., the headquarters for the N.E.C., can accommodate approximately 250 persons who wish

[*Continued on page 58*]

Signal Corps FM walkie-talkie being operated by soldier in training. Inset shows Handi-Talkie radio SCR-536 —*Signal Corps Photo*



ECHOPHONE MODEL EC-1

(Illustrated) a compact communications receiver with every necessary feature for good reception. Covers from 550 kc. to 30 mc. on 3 bands. Electrical bandspread on all bands. Six tubes. Self-contained speaker. 115-125 volts AC or DC.

ECHOPHONE RADIO CO., 540 NORTH MICHIGAN AVE., CHICAGO 11, ILLINOIS

New Products

NEW CAPACITRONS

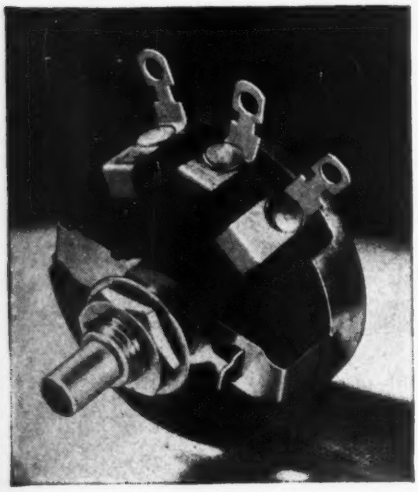
A new and complete line of rectangular oil-type capacitors has recently been announced by The Capacitron Company, 318 W. Schiller St., Chicago 10, Ill. Made in standard container sizes and in voltage ratings up to 6000 V.D.C.W., these new Capacitrons will meet Army and Navy

specifications, including total salt-water submersion tests.

Capacitron Bulletin 104 lists all pertinent data including capacities, voltage ratings, container sizes, types of terminals, and mounting arrangements.

NEW WIRE-WOUND CONTROL

A new version of the Type 58 Clarostat wire-wound potentiometer or rheostat has been recently released by Clarostat Mfg. Co., Inc., 285-7 N. 6th St., Brooklyn, N. Y. This is a still tougher control fully capable of coping with extreme vibration



and mechanical abuse such as encountered in wartime service, in addition to its electrical ruggedness.

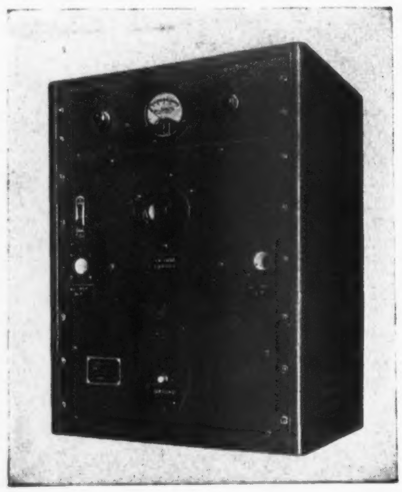
The new design differs somewhat from the previous Type 58. A metal strap on the shaft face provides for the two-position locating pin which cannot break or tear off. Also, the metal strap grounds the metal cover which is clinched to it. The cover is keyed in place on the casing and therefore will not loosen or turn. Fully dustproof. The bushing is keyed into the bakelite case and therefore cannot slip or turn when the locking nut is drawn up tightly. High-grade molded bakelite can eliminate corrosion and electrolytic action, especially when control is used on d.c.

The center rail and terminal comprise one piece. There is also a direct connection between winding and the "L" and "R" terminal lugs. Terminals are so constructed that melted solder cannot get inside the case to cause trouble.

There is zero hopoff at terminal. 1500 volt breakdown insulation between winding and shaft. Switch can be added. Minimum depth. Tandem units with two or more controls on common shaft, are available. Ratings: linear, 3 watts; V and W tapers, 2 watts; L, N and U tapers, 1.5 watts. Resistance values: linear, 1 to 75,-000 ohms; tapered, 10 to 50,000 ohms.

VOLTAGE-BREAKDOWN TESTER

A simple, positive, safe and quick means of testing voltage breakdown of materials or components is provided by the Type



P-3 Voltage Breakdown Tester recently released by Industrial Instruments, Inc., 17 Pollock Ave., Jersey City, N. J.

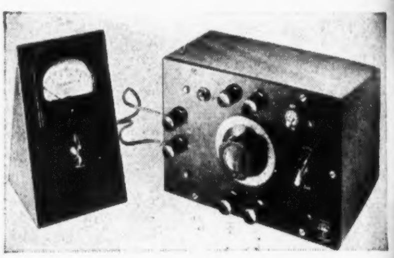
Operating range of instrument is 0 to 10,000 volts d.c., or 0 to 8,000 a.c. A lower range instrument, Type P-1, with sloping panel, has a range of 0 to 4,000 volts d.c., or 0 to 3,000 volts a.c. The voltage is continuously variable over the entire range.

The voltage-breakdown tester operates directly from 110-130 volt, 50/60 cycle line. A panel light indicates when instrument is "On." Breakdown is indicated by a red signal light, while the built-in meter indicates the direct-reading voltage. Current-limiting resistors safeguard the equipment in the event of a dead short, by limiting the current to approximately 50 milliamperes. Uniformity over the entire range on this model P-3, or 5 milliamperes on model P-1. To speed up production testing, drawer-switch type fixtures are available. These fixtures have a jig to take given components or materials, and when the drawer is closed the voltage is applied, with absolute safety for the operator. External connections are made by means of an insulated plug inserted in the high-potential a.c. or d.c. jack, with the other side grounded.

The voltage-breakdown tester is housed in a fine-grained crackled-enamel cabinet measuring 15" x 21" x 28" h.

NEW COMPARISON BRIDGE

Speedy testing of resistors, capacitors or inductors in terms of ohmage, microfarads or henries, respectively, is the pur-



pose of Type LB Direct-Indicating Comparison Bridge just released by Industrial Instruments, Inc., 17 Pollock Ave., Jersey City, N. J.

This production-test instrument is an a-c slidewire bridge with vacuum-tube null indicator arranged so that resistors, capacitors or inductors can be compared with a similar standard. Ranges are: Capacitance, between .0001 and 1.0 mfd.; Resistance, between 2000 ohms and 20 megohms; Inductance, between 5 and 50,000 henries. The slidewire is uncalibrated; external standards are used. In use, after the instrument is set up, the resistors, capacitors or inductors under test are connected one by one to the "X" terminals and are then rejected or passed by a direct reading of the indicating meter. Components outside the limits set up will result in a meter deflection greater than a set value. Operation is simple and rapid as the operator reads the meter directly, without rotating dials or pressing buttons. Limits may be set with any combination of high or low value, such as minus 6% plus 14%.

The instrument comprises the main unit with separate meter on stand, the former measuring 7" x 8" x 5½". Net weight, 6 lbs.

NEW TERMINAL BLOCK

The Curtis Feed-Thru Terminal Block consists of individual feed-thru terminals, molded in bakelite which are permanently

[Continued on page 54]

Here are TWO NEW TUBES in the Eimac line

Plate Dissipation (watts)	[illegible]	[illegible]
Amplification Factor	[illegible]	[illegible]
Filament Volts	[illegible]	[illegible]
Filament Current (am[illegible]	[illegible]	[illegible]
Interelectrode Capa[illegible]		
Grid to Plate	1.6	[illegible]
Grid to Filam[illegible]	2.5	[illegible]
Plate to Fila[illegible]	0.2	[illegible]
Maximum Ratin[illegible]		
(Class C ampli[illegible]		
Plate Voltage [illegible]	2000 volts	2000 volts
Plate Current [illegible]	75 mills	75 mills
Grid Current [illegible]	20 mills	20 mills
Maximum Plate Dissipation (watts)	25	25

Smaller brothers of the Eimac 35T and 35TG, these two triodes are filling a need in high-frequency equipment of relatively low-powered class. They attain a high order of efficiency on frequency in the VHF range and perform equally well at lower frequencies.

In every way these two are worthy additions to the Eimac family . . . embodying all the Eimac features including complete freedom from premature emission failures due to gas released internally.

Complete data is available without obligation. Write for it today. Also ask for your complimentary copy of *Electronic Telesis*, a sixty-four page booklet which gives the fundamentals of Electronics and many of its applications. Written in layman's language, this booklet will assist engineers in explaining the art to novices.

Follow the leaders to

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PART 2

The Terminology of ELECTROMAGNETIC THEORY

Because recent developments in the field of microwave radiation and generation have greatly widened the engineer's interest in electromagnetic theory, the following alphabetical list of terms, ideas, and theorems is presented. It is not so much intended that the discussions be rigorous definitions as that they shall give interesting ideas and serve as an introduction to the concepts.

Curl—The curl is an operator and generally has no properties assigned to it except as it works on a vector. In this respect it is like the operator (d/dx) or sine, which have no meaning except as they are prefixed before a symbol. Thereupon dy/dx symbolizes the slope of a curve which is a plot of y against x and sine θ represents a number somewhere between -1 and $+1$, depending on the value of θ. In the same way that the sine works on an angle and results in a number which we represent by sine θ, so when the curl operates on a vector such as A, it may specify a new vector which we call curl A.

The sort of vector which curl A symbolizes does not depend upon the magnitude or direction of A but only upon the way in which that magnitude and direction are changing. For example, if A is a vector representing the velocity of a point on the rim of a wheel rotating with an angular velocity ω, then curl A is a vector of magnitude 2ω, which points along the axis of the wheel in the direction of the progression of a right hand screw which turns with the wheel. *The curl of a vector is a new vector which describes the rotary motion of the first vector. It may be calculated by*

$$\text{curl } A = i\left(\frac{\delta Az}{\delta y} - \frac{\delta Ay}{\delta z}\right) + j\left(\frac{\delta Ax}{\delta z} - \frac{\delta Ax}{\delta x}\right) + k\left(\frac{\delta Ay}{\delta x} - \frac{\delta Ax}{\delta y}\right)$$

in rectangular coordinates, or by other well-known formulas in other coordinate systems. The resulting vector is, of course, independent of the coordinate systems in which A is specified and in which the calculation is made.

In Maxwell's equation, curl H is set equal to $I + \delta D/t$. If D is a constant then this becomes just curl $H = I$ and corresponds, for example, to a circular magnetic field H around a wire arising from a current, $I =$ curl H, flowing in the wire.

D'Alembert's Equation—Differential equations which have a particular form are often given names, usually the name of a man who made early use of the equation. Thus, equations are named after Bessel, Poisson, Lagrange, and D'Alembert. Contemporary writers do not always agree on these names. Such equations are found repeatedly in the study of physical phenomena and their properties become well known to students of theory so that whenever they appear, certain facts about the problem at hand are at once known.

For example, the well-known wave equation,

$$*\Delta^2 A = \frac{1}{v^2}\frac{d^2 A}{d t^2}$$

is one which appears in the study of acoustics, optics, hydrodynamics, quantum mechanics, and electricity. The meaning of the letter A will be different in each case, but always the equation will represent a wave of A moving through a medium. Moreover, the reciprocal of the square root of the coefficient of the time derivative term which we have represented by v will give the velocity with which the wave is propagated.

To be able to read satisfactorily mathematical discussions it is very helpful to become acquainted with at least some of the properties of as many such equations as possible. *D'Alembert's equation* is

$$*\Delta^2 A - \frac{1}{v^2}\frac{d^2 A}{d t^2} = f(x, y, z, t)$$

It is of particular interest because it may be interpreted as a basic relation derived and defined from Maxwell's equations to dictate all antenna patterns when the current and charge in the antenna are known. In order, however, for D'Alembert's equation to do this, it is necessary that A shall not directly represent the electric and magnetic fields but rather shall indicate potential functions which when once found make possible the calculation of E and H. For the electric field the potential function is ordinary electric potential and f (x, y, z, t) is a term representing charge and its distribution in space and time. For the magnetic field, A represents a vector potential defined in a rather special way and the right-hand member of the equation is an expression for current density.

An interesting property of D'Alembert's equation is that in the absence of charge and current it reduces to the wave equation referred to before. When the charge and current are constant with time the equation becomes Poisson's equation, and we find ourselves dealing only with electrostatic and magnetostatic phenomena. It is also noteworthy that certain solutions of D'Alembert's equation involves what is known as retarded potentials. This corresponds to the fact that the field at a point in space depends upon charge and current at other points of space as they existed at previous times in order to account for the finite time of travel of electromagnetic energy.

Decibel-db—The importance of a variation in a physical quantity is sometimes dependent only upon the amount of variation, but more often it is also dependent upon the size of the quantity in question. The decibel is particularly suited to the measurement of the change in a physical quantity when the portion of the quantity represented by the change is of primary interest. It gives a linear measure of the *effect* of such a variation.

In communication work the decibel is most commonly used to measure power ratios. *If the powers being compared are P_1 and P_2, the ratio of these powers as expressed in db is*

$$\text{Power ratio in db} = 10 \log_{10} \frac{P_1}{P_2}$$

If a certain radio signal is said to be raised in level by 3 db its power has been doubled. Ten db corresponds to a power ratio of 10, 20 db to 100, 60 db to 1,000,000, etc. The practical value of the unit arises from the fact that these ratios of power gain or loss as expressed in db come nearer to

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counter it than do direct power ratios. A 60-db loss in signal comes nearer to reducing the usefulness of the signal by a factor of 60 than it does by a factor of 1,000,000. The very large ranges of power involved in communication work can be expressed in terms of decibels without using inconveniently large numbers.

When db are used to specify the voltage or current gain of an amplifier, care must be taken in the interpretation. If the two voltages to be compared are measured across equal resistors, the voltage and current gains or losses in db will be just twice the power gain or loss. If the loads are not equal resistors the relation is more complicated.

The neper is another unit which is sometimes used to fulfill the same purpose as the decibel. It is defined by

$$N = \frac{1}{2} \log_e \frac{P_1}{P_2}$$

To convert nepers to db, multiply by 8.686.

The decibel was originally used in the acoustical measurement of sound levels. The British have recently introduced the phon as a specific unit of loudness. It is supposed to measure loudness as perceived by the ear quite independently of frequency. The loudness of sound in phons is numerically equal to the sound intensity in decibels of an equally loud 1000-cycle pure note as compared to the intensity of sound at the average lower limit of audibility, which has been standardized upon as 10^{-16} watts per square cm.

***Del.**— The symbol Δ, which is the Greek letter delta printed upside down, is commonly used to represent a certain operator. *In Cartesian coordinates it is*

$$\Delta i \frac{\delta}{\delta x} + j \frac{\delta}{\delta x} + k \frac{\delta}{\delta x}$$

where i, j, and k are, respectively, unit vectors along the x, y, and z axes. It is a very convenient symbol because of its purely formal versatility. It has no meaning by itself, but when treated like a vector quantity and multiplied by a scalar quantity in the way that is usual with a real vector, then upon performing the differentiation which the formal multiplication indicates, the gradient of the scalar results. ΔS = grad S. Likewise, if the steps of taking the scalar product of del with a vector are carried through, the divergence of the vector results. If the vector product is made the curl is obtained.

The operator Δ^2, which indicates that the symbol following it should be formally multiplied by Δ twice, is of particular interest. It is called the Laplacian operator and $\Delta^2 S = 0$ is called Laplace's equation. In words $\Delta^2 S$ means the divergence of the gradient of S. Laplace's equation, $\Delta^2 V = 0$ is the one which tells the potential at any point in free space arising from stationary charge. The location of the charge determines the boundary conditions under which a solution of the equation is written.

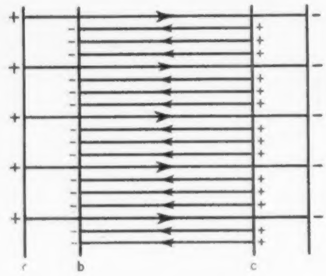
A particular advantage of writing Laplace's equation with Δ^2 is that the meaning is clear, quite independent of the coordinate system. In Cartesian coordinates

$$\Delta^2 \text{ is } \frac{\delta^2}{\delta x^2} + \frac{\delta^2}{\delta y^2} + \frac{\delta^2}{\delta z^2};$$

in other coordinate systems it is a rather more complicated expression. The system that is chosen for a given problem is a matter of convenience. In a general derivation, however, we need not commit ourselves and relations such as Laplace's equation can later be written in terms of whatever coordinates we desire.

* Delta is shown because there is no symbol available for del.

Dielectric Constant-ε— If the electric field E is defined as the field arising from all charge and the electric displacement D is defined as the field due only to free charge, we may reasonably make the definition that *ε is equal to D/E.* If only free charge is injected into empty space then both D and E measure the same field and ε becomes a number depending only on the units assigned to D and E. In a dielectric ε will take on a somewhat smaller value.



Charge distribution diagram.

A qualitative explanation is best given in terms of the polarization of bound charge. Dielectrics are made up of paired positive and negative charges which, however, are in general oriented at random so as to give rise to no net field. When the dielectric is stressed by the presence of "real" charge the polarization charges are somewhat aligned and the effect of a charge distribution on the faces of the dielectric is obtained. If surfaces *a* and *d* carry free charge as indicated and the volume between planes *b* and *c* is filled with dielectric, the bound charges in the dielectric tend to align themselves so as to give the effect of a charge distribution on surfaces *b* and *c*. If the field is measured in the medium without creating new interfaces on which the lines from the polarization charges may end, the field E in the medium is measured. If a measurement is made between planes *a* and *b*, a value of the field is obtained that is equal to D in the medium.

Quantitatively we write $D = E + 4\pi P$, where P is the sum of the dipole moments per unit volume or, more simply, a measure of the amount of polarization arising from a given field D. It is clearly desirable that P be proportional to E so that $P = KE$ and $D = E\ (1 + 4\pi K) = \epsilon E$. This is fortunately true or approximately true for most media.

Dielectric Constant in Free Space-ϵ_0— In the Giorgi or MKS system of units ϵ_0 and the permeability of free space are two numerical quantities which must be remembered in order to keep the units straight. In that system E is measured interms of volts per meter and D in coulombs per square meter. Since, in a vacuum, E and D measure the same thing and since by definition $\epsilon = D/E$, it follows that ϵ_0 is just the ratio of the unit sizes. In other words ϵ_0 represents the number of coulombs per square meter which corresponds to one volt per meter. To evaluate ϵ_0 we thus need to ask what positive charge density on an infinite plane will make it necessary to use a potential of one volt to hold a positive charge of one coulomb in front of that plane.

This is a simple problem although one which needs some care in transforming the electrostatic units, in which Coulomb's law is normally stated, to units of the MKS system. Its solution indicates that *in the MKS system $\epsilon_0 = 8.85 \times 10^{-12}$ farad per meter.*

In the so-called Gaussian units, ϵ_0 has a value of unity. This is simply because there E and D have units which cause them to give the same numerical value of a field in a vacuum. This unity value of ϵ_0 is very convenient in some calculations and causes many people occasionally to employ Gaussian units, but it is a rather big price to pay for the many other conveniences of the Giorgi system.

Diffraction, Fraunhofer — *This type of diffraction is characterized by the focusing of energy after it passes through, or bends around, the edges of one or more apertures.* As with the optical case illustrated by the telescope, the resolving power of a high-gain antenna may be limited by Fraunhofer diffraction.

Suppose two neighboring but very distant microwave sources are distinguished by the use of a high-gain antenna. If the aperture of the receiving antenna is large this may be possible. If, however, an adjustable aperture is used and its size gradually reduced, Fraunhofer diffraction may so spread the apparent direction of energy reception from each source as to preclude their resolution.

Diffraction, Fresnel—Following the terminology used in the study of optics, *the ability of radio waves to travel in other than straight lines, to appear behind an obstacle, or otherwise cast shadows of unexpected shape is called diffraction. When no focusing occurs after the obstacles are passed, the diffraction is specifically referred to as Fresnel diffraction.*

This phenomenon has nothing to do with reflection from a layer of ionized air in the stratosphere nor with the ability of long electromagnetic waves to penetrate optically opaque materials. Likewise, it is not directly connected with the refractive bending of a beam of electromagnetic waves as they pass from one medium into another. Rather it is a fundamental property of wave motion which always allows at least some energy to turn corners.

The amount of energy which is diffracted depends upon the dimensions of

[*Continued on page 48*]

The HARVEY Regulated Power Supply 106 PA

You'll find it ideal for operation with pulse generators, measurement equipment, constant frequency applicators, amplifiers and any other equipment requiring a constant flow of D. C. voltage.

Designed to operate from 115 volts A. C., the HARVEY 106 P A has a D. C. voltage output variable from between 200 to 300 volts and accurately controllable *to within one per cent.* A model of efficiency and convenience, it has separate fuses on each transformer primary as well as the D. C. output circuit: pilot lights on each switch; a D. C. voltmeter for measuring output voltage and a handy two-prong plug or binding posts to permit easy hook-up.

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[*Continued from page 46*]

the objects in relation to the wave length of the radiation and upon the geometry of the space being investigated. If an opaque obstacle is placed in the path of a beam emerging from a small source, the width of the shadow is not only greater than is to be expected by straight line geometric construction but may have boundaries which are bordered with further shadow bands.

If a slit of proper width is installed in a large opaque plane and one side of that plane radiated with energy from a small source, it will be found that energy is radiated through the slit over a much wider angle than would be expected. The more the slit is narrowed, the greater is the angle of coverage. If a small circular object of correct dimensions is placed in a conical beam, energy will be found at a distance behind the object exactly at the center of the shadow which the object is expected to cast.

These and other similar phenomena are examples of Fresnel diffraction. In optics as with radio waves the effects are closely connected in magnitude with the wave length of the radiation. Thus the optical patterns are usually of small extent in space. With radio waves all dimensions are much larger and, at least in some cases, the phenomenon is more important.

Divergence-div—Divergence, like the curl, is an operator and has no physical meaning associated with it except as it works on a vector. If, however, A is a vector which is a function of the coordinates of a given space so that it takes on a particular value at every point of the space, then div A has a definite physical meaning. *The divergence of a vector is a scalar quantity which tells the net amount of flow out of a unit volume.*

In the Maxwellian equation, div $D = 4\pi\rho$, the generation of an electric displacement field by real charge is described. At those points in space where there are no charges or where there is only bound charge, any small volume will contain a zero value of the charge density, ρ. This means that div $D = 0$, and necessarily the same number of lines of D enter the volume as leave it. Since the volume may be made as small as we wish down to atomic dimensions, it also means that the lines of D are continuous in such regions. On the other hand, at a point in space where charge does exist, the number of lines of D leaving a small volume in which the charge is located will exceed the number entering by an amount equal to the number of lines originated by the charge. At such a point ρ has a finite value and dictates that div D shall represent a number showing this increase in flux.

The divergence of a vector is useful in describing almost any vector field. It is commonly illustrated by a reference to hydrodynamics where the field represents the velocity of flow of an incompressible liquid. In that case the divergence is zero everywhere except at sources or sinks. In Cartesian coordinates

$$\text{div} = \frac{\delta}{\delta x} + \frac{\delta}{\delta y} + \frac{\delta}{\delta z}.$$

Electric Dipole—If equal amounts of positive and negative charge are distributed at random in a given volume, that volume as a whole may be said to be uncharged. It may also be that in the neighborhood of such a volume there is no electric field or at least none whose source can be traced to the mixture of positive and negative charge.

As a matter of fact, this is the situation with all uncharged physical bodies. The individual atoms of the body contain both positive and negative charge but in such small units and so well mixed that they are not detectable by ordinary methods of measuring electromagnetic fields.

When only a single positive and a single negative charge are involved, however, the situation is somewhat different. Except when they are actually coincident with each other such a pair of charges does give rise to a field. Because charges (electrons, etc.) do occupy finite volumes it is of course impossible that they really be coincident; but, since an element of charge may be very small, we can conceive of the charges being so close together that ordinary small volumes will be uncharged even though they contain an electric dipole.

An electric dipole is made up of a posi-

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tive and a negative charge which are of equal strength and are placed at a small distance apart so that no net charge is present and yet an electric field is generated. At distances large compared to their separation, r, the field arising from a dipole is

$$E = r_1 \frac{2P\cos\theta}{r^3} + \theta_1 \frac{p\sin\theta}{r^3}$$

where θ is the angle between a line connecting the charges and a line drawn from the charges to the point of observation, p is the dipole moment, and r_1 and θ_1 are unit vectors pointing respectively along a radial vector drawn toward the point of observation and one constructed perpendicular to that radial vector in a plane determined by the position of the two charges and the point where the observation is made.

The dipole moment is a quantity which is often mentioned in talking about dipoles. It is the product of the charge (either the positive or the negative one) and the distance r. As can be seen in the expression just given, it is the dipole moment which determines the strength of the dipole as measured in terms of field strength.

Electrostatic Units-e.s.u.— *For calculations which concern themselves only with stationary charge and therefore do not deal at all with magnetism, the electrostatic system of units is the logical and simplest choice of notation that can be made.*

The e.s.u. coulomb, defined as the amount of charge which will exert a force of one dyne on an equal charge one cm away, forms the basis of the system. The electric field E then becomes just dynes per coulomb, potential becomes ergs per coulomb, and the electric displacement D is defined to be equal to E in a vacuum by virtue of defining ε_0 equal to unity.

If an attempt is made to carry this system of units over into the study of magnetic phenomena, a rather awkward arrangement is obtained and no logical justification for doing so can be found. For example, an e.s.u. ampere is an e.s.u. coulomb per second and expressions such as $F = BIL$ for the force on a wire carrying current through a magnetic field would call for the use of electrostatic units of B which are inconveniently large, being 3×10^{10} times as large as a gauss. In such a system we would find ourselves ordinarily dealing with small fractions of a unit of B, which could easily lead to errors of statement.

Electrostatic units are often referred to as statcoulombs, statvolts, statfarads, etc.

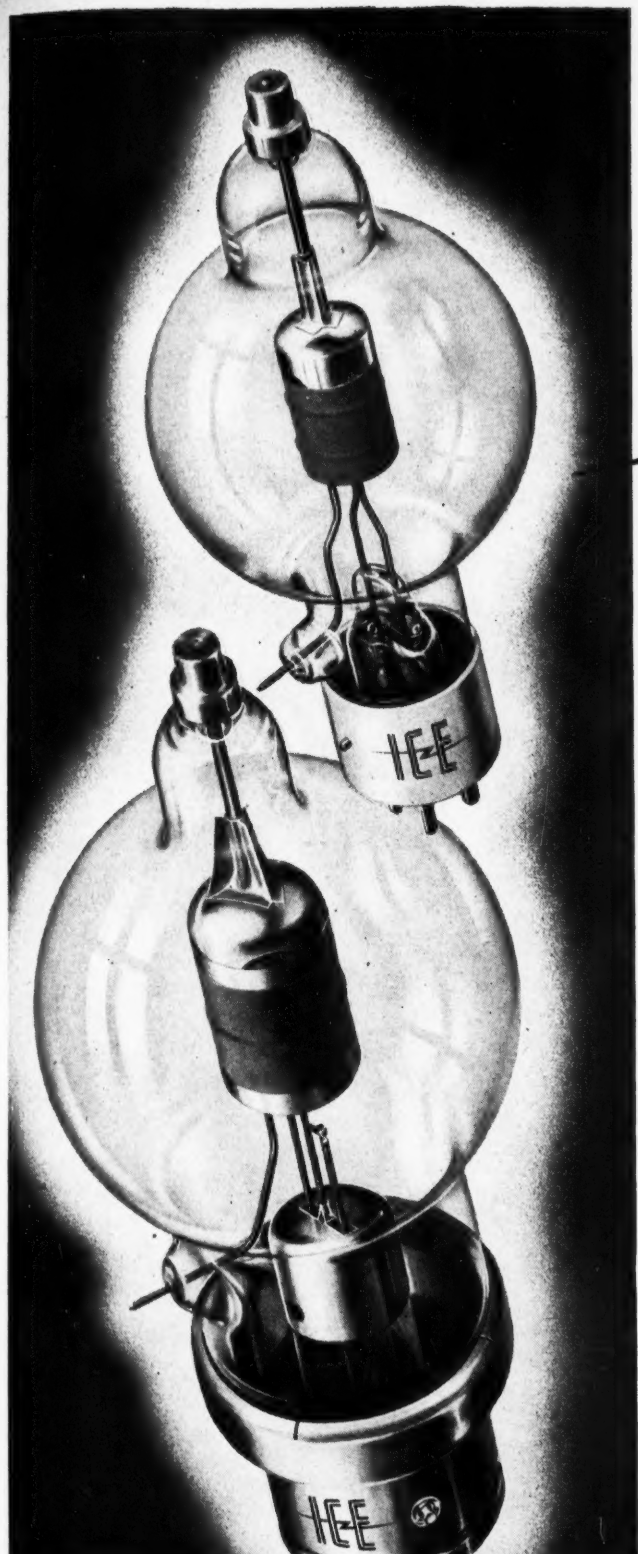
Equation of Continuity— The equation of continuity is a mathematical statement to the effect that a quantity such as a charge can not magically appear or disappear anywhere in space. In its most general form it may be stated as

$$\iiint \frac{\delta\rho}{\delta t}\, dv = -\iint f_n ds + \iiint P dv$$

This equation considers a small volume of space dv. The left member expresses the total rate of change of material in that volume since $\delta\rho/\delta t$ is the rate of change of density and the integral signs indicate summation over the volume. The first term of the right-hand member represents the flow of material into the volume. The symbol f_n represents the component of the flow normal to the surface, the minus sign indicates the inward direction of the flow, and the double integral with ds shows that the flow is to be added up over the surface of dv. P is the rate of production within the volume. Thus, in words, the equation of continuity may be stated as: *The rate of increase of material in a given volume is equal to the amount flowing in plus the amount produced in the volume.*

In a steady state where density is independent of time we may simply write div $f = P$, which says that the rate of efflux is equal to the rate of production. The equation of continuity is a useful relation in many problems involving vector and scalar fields. For example, the basic contribution of Maxwell to electromagnetic theory may be shown to hinge on this

[*Continued on page 52*]



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BELMONT, CALIFORNIA

TERMINOLOGY

[*Continued from page 50*]

relation. Ampere's circuital law, which may be written as curl $H = 4\pi u/c$ in Gaussian units, does not obey the equation of continuity. This may be seen by taking the divergence of each side of the equation and recognizing that the divergence of any curl is always zero, in contradiction to the divergence of the current, which is certainly not always zero; for example, a charge may be allowed to accumulate on the plates of a condenser. Maxwell therefore added the term $\frac{1}{c}\frac{\delta E}{\delta t}$, which caused the equation to become completely rigorous.

Equivalence Theorem— To obtain a given electric and magnetic field in a source-free section of space, it is not necessary to maintain a unique array of currents and charges. For example, the magnetic field in a region at the center of a long solenoid is given in oersteds by $H = 4\pi nI/10$, where n is the number of turns per cm in the solenoid and I is the current in amperes.

The same field is obtained in the region under observation even if the position of the currents in space are changed by increasing the radius of the long solenoid. Likewise, if a region between two large charged plates is examined, an electric displacement field of V/d is found in which V is the potential between the plates and d the distance. The same field is maintained in the region under consideration by charges on plates separated by a different distance if the voltage is changed a compensating amount. Specifically, the plates may be placed so as to form part of the boundary of the observed volume.

Stated more generally in a form which is sometimes referred to as an equivalence theorem, we may say that *any field in a source-free region bounded by an imaginary surface can be produced by a distribution of electric and magnetic currents on that surface.* Thus any actual currents and charges anywhere in space which generate a certain field in a limited region may be replaced as far as that region is concerned by other electric and magnetic currents on the surface of the limited region.

At least one application of this theorem is possible in the study of microwaves. It has to do with the calculation of the radiation fields coming from an opening in a wave guide or resonant cavity. The actual currents from which these radiation fields arise are very difficult to know with precision. Instead of trying to calculate them and then use the Biot-Savart law or some more elegant method of field calculation, it is sometimes simpler to consider all space outside the wave guide or cavity as the limited source-free region and replace the opening and wave guide surface by real and equivalent currents. These may be calculated from actual field measurements at the opening and then the radiation field computed as arising from the equivalent currents.

Faraday Induction Law— The discovery that a changing magnetic field gives rise to an electric potential is generally attributed to Faraday and the statement that *around any closed path an electromotive force is generated by a changing magnetic flux through the circuit formed by that path* is generally called the Faraday Induction Law.

Quantitatively, the law may be stated as

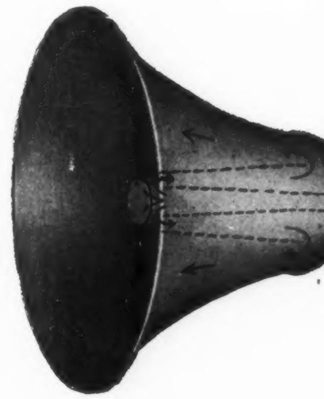
$$E = -\frac{\delta N}{\delta t}$$

where E is the voltage generated in e.m.u. volts, and N is the total flux of B through the loop in gauss cm.^{2}. A partial derivative is written because N in general may be a function of coordinates as well as time. The minus sign is a matter of convention and indicates that the field must be decreasing to generate a voltage around the circuit in the direction that a right-hand screw would turn to move forward in the direction of the magnetic field.

It should be emphasized that the Faraday Induction Law applies to any closed path whether there is a conductor present along that path or not, although only if a conductor is present can a current be made to flow. Thus, in a wave guide or resonant cavity which is fed magnetically by circulating a varying current through a loop inside the device, the changing magnetic field can cause a voltage or electric field to appear at appropriate places and create an internal energy flow in accordance with Poynting's vector.

[*To be continued next month*]

A Safe Bet for Steady Sales

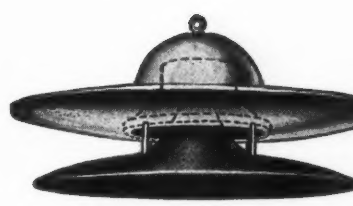


Left—**MARINE SPEAKER; approved by the U. S. Coast Guard, for all emergency loudspeaker systems on ships. Re-entrant type horn. Models up to 50 watts. May be used as both speaker and microphone.**

Right—**RE-ENTRANT TRUMPET; available in 3½′, 4½′ and 6′ sizes. Compact. Delivers highly concentrated sound with great efficiency over long distances.**

Left—**RADIAL HORN SPEAKER; a 3½′ re-entrant type horn. Projects sound with even intensity over 360° area. Storm-proof. Made of RACON Acoustic Material to prevent resonant effects.**

Right—**AEROPLANE HORNS; super-powerful and efficient P.A. horns for extreme range projection. 9 and 4 unit Trumpets available.**



Left—**PAGING HORN; extremely efficient 2′ trumpet speaker for use where highly concentrated sound is required to override high noise levels. Uses P.M. unit.**

Right—**RADIAL CONE SPEAKER; projects sound with even intensity over 360° area. Cone speaker driven. Will blend with ceiling architecture. RACON Acoustic Material prevents resonant effects.**

SEND FOR CATALOG

RACON, pioneer and world's largest manufacturer of loudspeakers, horns and driving units, is working at capacity filling diversified orders — speakers for Army, Navy, Maritime Commission and industrial use. Now we are planning ahead.

Practically all industrial firms are users, or potential users of some type public-address, paging or sound distribution system. Statistics prove that a properly planned sound system installation is a good investment which in time generally pays for itself.

RACONS have always enjoyed a steady, high sales volume. We believe they always will, for our products are the finest that money can buy, or engineering skill produce. Receiver units supplied with either metal or plastic diaphragms. RACON products generally cost less than competitive brands because a lower power-rated and lower-priced RACON will outperform higher power-rated units of other make. In other words, don't let catalog list-prices fool you. Basic costs and rated outputs are the prime factors worth considering. That's why leading soundmen prefer and specify RACONS, they are dependable—a safe bet for steady sales and satisfied users.

RACON ELECTRIC CO. 52 EAST 19th ST. NEW YORK, N. Y.

NEW PRODUCTS

[*Continued from page 42*]

held in a metal strip in any combination desired. Factory production now includes blocks having any number of units between 1 and 16, but, because of their unique sectional design, blocks can be supplied with any number of terminals needed.

Terminals have ample clearances and leakage distances for circuits carrying up to 300 volts, 20 amperes. Center to center distance between terminal units is ⅝". No. 8 screws are used on each side of terminal units for securing connection. The two mounting holes at each end of the terminal base take No. 8 machine screws. These new blocks, known as Curtis Feed-Thru Terminal Blocks are offered by Curtis Development and Manufacturing Company, 1 No. Crawford Avenue, Chicago, Illinois—Factory, Milwaukee, Wisconsin.

Descriptive literature is available upon request to manufacturer.

TAPE INSULATION

"Fibron," a new many-purpose plastic tape of widely divergent applications, has been announced by Irvington Varnish & Insulator Company, Irvington 11, N. J., as the most recent addition to its line of insulating products. It is used for insulating wire, cables and electrical equipment; for splicing cables; and for protecting wiring, piping, and equipment exposed to caustic or corrosive fumes, oil, grease, acids, alkalis or moisture.

Fibron Tape is manufactured from "Vinylite" resin, a product of the Carbide and Carbon Chemicals Corporation. It is heat-sealing, flame resistant, and high in dielectric and mechanical strength.

To introduce Fibron Tape, a general sample for testing will be sent by the manufacturer on request.

NEW CAPACITOR CATALOG

The new Sprague Dry Electrolytic Catalog No. 10 will prove of timely interest to those charged with selecting capacitor types for a given application. The Catalog presents graphic evidence of the rapid advancement in dry electrolytic types in

recent years, including types to match exacting war equipment needs.

Sprague Dry Electrolytic Capacitors have been steadily developed to a point where they meet exacting applications. These include salt air, reduced pressure, low and high temperature extremes, transients, r-f impedance, sealing "shelf life," and many more. Also, as fully explained in this new 28-page catalog, they are available with special electrical characteristics and in containers for every mechanical requirement. Of particular importance to engineers and designers, many pages are devoted to application notes including a number of typical characteristic charts.

A copy of the catalog will be sent on request to the Sprague Electric Company (formerly Sprague Specialties Co.), North Adams, Mass. Ask for Dry Electrolytic Capacitor Catalog No. 10.

NEW GENERATOR

A new type hand generator with a maximum output of 100-watts has been developed by the Carter Motor Company, 1608 Milwaukee Ave., Chicago. Not only is the unit the largest permanent magnet hand generator manufactured (thus saving about 10-watts of power usually required for activating the field coils), but it requires no outside electricity of any kind to operate. Two men turning improved cranks can, by watching the meter, observe that the output is held to the correct value.

The stand comes complete with seats and is collapsible, while a chain keeps the legs from spreading beyond holding position when the unit is set up.

The hand generator is made of cast aluminum to reduce weight and corrosion and delivers a wide range of outputs up to 500 volts d.c. and a filament output voltage. 117 volts a.c. output is also available. It weighs only 37 lbs.

H-F GENERATORS ANNOUNCED

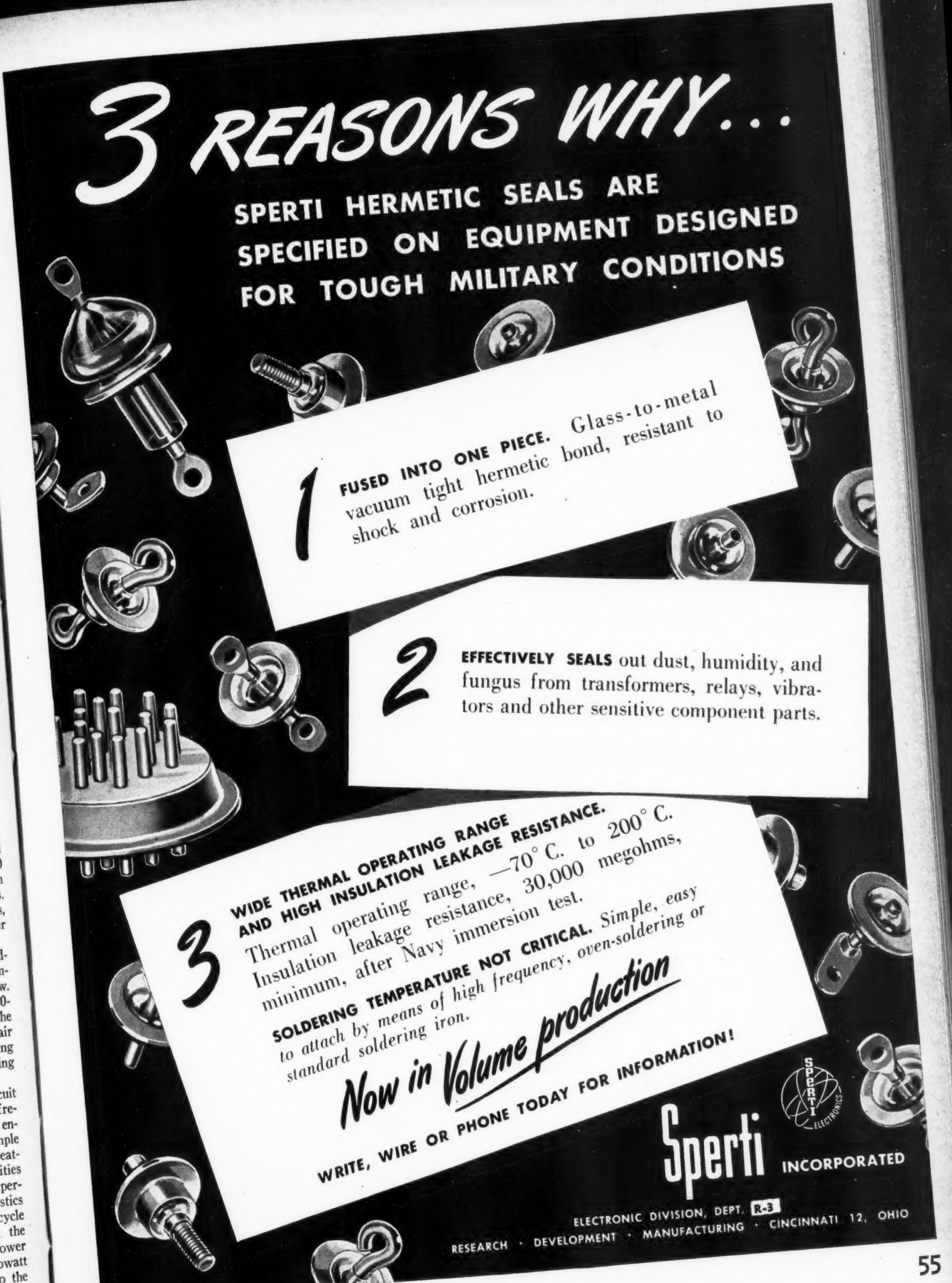
For both induction and dielectric heating loads, a complete line of high frequency generators with ratings of 1, 2, 5, 10 and 20 kw. in line with NEMA standards is announced by Westinghouse Electric and Manufacturing Company.

Completely self-contained, the units require only electrical connection to a 60-cycle power supply and have no external cooling or other auxiliaries. Units of 50 to 200 kw. capacity can be supplied in addition to standard one to 20-kw. ratings. The primary voltage is 220 or 440 volts, single phase for ratings of 5 kw. or lower and 3 phase for 10 kw. and higher.

Air-cooled tubes are used in the standardized generators. Their use allows complete portability of the 2-, 5-, and 10-kw. units and increased portability of the 20-kw. unit. The air blower for cooling the tubes provides a circulation of air throughout the entire equipment, insuring a greater factor of safety and permitting a reduction in size.

The high-frequency oscillating circuit varies with the kilowatt rating and frequency needed. The circuits selected entail the least number of controls, are simple to adjust and operate and have the greatest overall efficiency. For capacities through 10-kw. the type of circuit permits frequency shift as the characteristics of the load change during the heating cycle in such a manner that the load on the tube anode tends to approach unity power factor. In the two, five and ten-killowatt generators, the load can be coupled to the

[*Continued on page 56*]


3 REASONS WHY...
SPERTI HERMETIC SEALS ARE SPECIFIED ON EQUIPMENT DESIGNED FOR TOUGH MILITARY CONDITIONS
1 FUSED INTO ONE PIECE. Glass-to-metal vacuum tight hermetic bond, resistant to shock and corrosion.
2 EFFECTIVELY SEALS out dust, humidity, and fungus from transformers, relays, vibrators and other sensitive component parts.
3 WIDE THERMAL OPERATING RANGE AND HIGH INSULATION LEAKAGE RESISTANCE. Thermal operating range, —70° C. to 200° C. Insulation leakage resistance, 30,000 megohms, minimum, after Navy immersion test.
SOLDERING TEMPERATURE NOT CRITICAL. Simple, easy to attach by means of high frequency, oven-soldering or standard soldering iron.
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RESEARCH · DEVELOPMENT · MANUFACTURING
SPERTI ELECTRONICS

NEW PRODUCTS

[*Continued from page 54*]

work without the use of an external impedance-matching network when the work and generator are close together. A separate network is available for greater distances to the work and for use with the 20-kw. unit.

Generators are available for frequencies of 450 kc, 5, 15 and 30 mc for ratings through 10 kw. and 450 kc, 2 and 10 mc for 20 kw. and higher. This range of frequencies provides for adequate handling of all types of induction and dielectric problems.

Further information on the new high frequency generators may be secured from Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

NEW TYPE STORAGE BATTERIES

Employing the "vacuum-pack" principle which has been extensively used for preserving and safeguarding foods, an unusual type of storage battery, developed by the Willard Storage Battery Company, is now being mass-produced for use by our armed forces. Details of these new batteries and their unique packing have just been revealed.

Four batteries—three 36-volt types and one 6-volt—are packed in a lead-plated metal container from which the air is exhausted. The batteries retain their charge indefinitely and are ready for immediate use regardless of the time elapsed since their manufacture, or the distance they have been transported from the Willard factory.

When the batteries are about to be placed in service, the can is punctured by a special filling device and the vacuum inside the can draws the electrolyte quickly into the 18 miniature vent holes in each battery. Thus, in a matter of seconds, each battery is filled with electrolyte and is ready to go to work. It is were not for the vacuum-pack idea, each of the 18 individual cells in each battery would have to be filled separately by means of a hypodermic syringe.

The batteries themselves are even more unusual than the method used in packing them. The 36-volt type, described by Willard engineers as the smallest high-coltage storage battery ever built commercially, measures slightly over four inches in length, just under one and a half inches in width and less than an inch in height, and weighs six ounces. Its case is made of polystyrene plastic—a material which is immune to electrolyte corrosion, lighter than glass, stronger than hard rubber, and readily moulded to required shapes and dimensions.

Major use of these Willard "vacuum-packs" is the supplying of power for a remarkable aerial radio device, known as the radiosonde, which broadcasts records of humidity, temperature and pressure from stratospheric heights and assists greatly in forecasting weather and flying conditions.

COAX SOLDERING SIMPLIFIED

A new and exclusive feature developed by Andrew Co., Chicago 19, Illinois, makes soldering of coaxial plugs and jacks an easy and "out in the open" job. Built in sliding sections, the plugs and jacks are easily disassembled and the conductors to be soldered are easily and quickly exposed by removing one screw and sliding the sections apart with the fingers. It is not necessary to solder through a window. This latest development in coaxial plug and jack construction makes soldering quicker and allows the workman to do a better job.

TIMING DEVICES

Haydon Manufacturing Company, Inc., Forestville, Conn., continues to announce new and valuable timing devices now available. The 5900 series comprises synchronous motor-operated automatic reset time delay and interval timers for time delays of one second to five minutes with fixed or adjustable intervals.

These units are available with various assemblies of actuating arms, reset springs, terminal mountings and precision snap switches, NC, NO and DT.

Where specified, for shock and vibration applications, the motor can be equipped with a special 4193-2 shift counterweight assembly. Timers so equipped are given a 30 cycle per second ⅛" amplitude vibration test before leaving the factory.

The 5900 series type, fixed interval reset timer for timed periods up to one minute may be indefinitely stalled across the line. Because of the larger torque built up in the motor at slower speeds than 1 RPM, where a longer period is required, it is necessary to use an auxiliary relay to release the timing motor at the end of the timed period.

With the adjustable time delay units available (1817 series) a 5 RPM motor is ordinarily used to give an adjustable delay of 1-10 seconds, etc. The adjustment is set by means of a stopnut which controls the position of the stop against which the motor arm resets at the end of return travel. In the adjustable units for timing intervals of 10 seconds to 5 minutes, a correspondingly slower speed motor is used, depending on the timed period requested by the customer.

On all timed periods of less than 30 seconds, the adjustable style units is recommended.

These units are also available (5148 series) for d-c operation.

PILOT LIGHT DATA

A new booklet containing 24 pages of pilot light illustrations, diagrams, specifications, prices and other pertinent information has just been published by the Gothard Manufacturing Company, 1300 North Ninth Street, Springfield, Illinois, under the title "Gothard Pilot Light Assemblies for Panel Board and Instrument Signaling."

THIS MONTH

[*Continued from page 40*]

to make this their Conference headquarters, in its single and double rooms. The Club will be pleased to reserve rooms in the nearby North Side Hotels to accommodate any overflow. Those persons planning to attend the Conference are urged to make their hotel and train reservations at an early date.

Professor P. G. Andres, Chairman of the Arrangements Committee, announced that his committee would be equipped to accept registrations for the Conference by September 1. Important groups in the electronics field will be circularized by mail and may return the registration card, with which they will be supplied, to Prof. P. G. Andres, Illinois Institute of Technology, 3300 Federal Street, Chicago 16, Illinois. Advance registration by mail is desirable to facilitate the rapid handling of registration during the Conference.

A refreshing program of activities to balance the rather concentrated technical conference is also being developed by Prof. Andres as part of the regular Conference activities.

Further information concerning details of the Conference may be obtained from:

Dr. J. E. Hobson, Chairman, Executive Committee, Illinois Institute of Technology, 3300 Federal St., Chicago 16, Ill.

Prof. A. B. Bronwell, Chairman, Program Committee, Northwestern University, Technological Institute, Evanston, Ill.

Prof. P. G. Andres, Chairman, Arrangements Committee, Illinois Institute of Technology, 3300 Federal St., Chicago 16, Ill.

Dr. B. Dudley, Chairman, Publications and Publicity Committee, 520 N. Michigan Ave., Chicago 11, Ill. Room 1210.

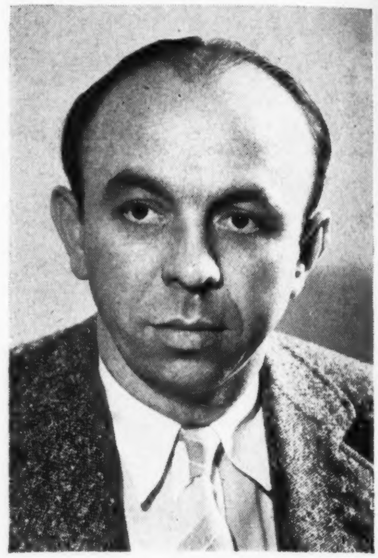
The National Electronics Conference is sponsored by the Illinois Institute of Technology, and Northwestern University as participating sponsors, and the Chicago Sections of the American Institute of Electrical Engineers and the Chicago Section of the Institute of Radio Engineers as cooperating sponsors.

RMA ELECTS COLE

S. I. Cole, president of Aerovox Corporation of New Bedford, Mass., has just been elected a director of the RMA Parts Division for the two-year term beginning 1944. This prominent condenser manufacturer was a member of the Executive Committee of the RMA Parts Division during 1943. In his new appointment he brings a wealth of radio parts manufacturing and distributing experience to the entire radio and allied industry.

NEW TAYLOR EXECUTIVES

Frank J. Hajek, formerly Secretary and Treasurer and associated with the company since its beginning, takes over all phases of management by being elected to fill the post of President of Taylor Tubes, Inc., 2312 Wabansia Ave., Chicago; while *James C. Filmer,* for many years a leading electronic tube engineer, has been appointed Vice-President in Charge of Engineering, in a move to gear the firm to the high-speed post-war conversion period which is rapidly approaching.



Frank J. Hajek

Joseph F. Hajek becomes Secretary and Jerry Worrel, Treasurer, of the company.

With the shift in executive personnel comes word that a new and drastically unique distributor policy is being worked out and will shortly be announced by Rex L. Munger, Sales and Advertising Manager, who but recently returned from war duty with Douglas Aircraft Corp., to head up the Sales Department, a post he had held for a long time prior to the war.

RCAC APPOINTS MITCHELL

Lieut. Col. Thompson H. Mitchell has been appointed General Manager of R.C.A. Communications, Inc., it was announced today by Lieut. General J. G. Harbord, Chairman of the Board of Radio Corporation of America. Colonel Mitchell succeeds the late William A. Winterbottom who had served as Vice President and General Manager of RCAC since formation of the Company until his death on July 8. Confirmation of Col. Mitchell as Vice President is anticipated when the Board of Directors of RCAC meets.

APCO CONFERENCE

The 11th Annual National Conference of the Associated Police Communication Officers will be held at the Commodore Perry Hotel, Toledo, Ohio, September 18, 19 and 20, 1944.

The serious Manpower situation, Frequency Allocation, Inter-City Communications and Interference Problems are some of the important discussions of this three day Conference which will bring together the leading Polic Communication men of the United States. Also, representatives from the Federal Communication Commission will have a prominent place on the program.

Toledo was chosen for this important war-time conference because of its central location and accessibility. Headquarters hotel, The Commodore Perry, is one of the finest in the State of Ohio. Our mem-

[*Continued on page 60*]

History of Communications Number Seven of a Series

THIS MONTH

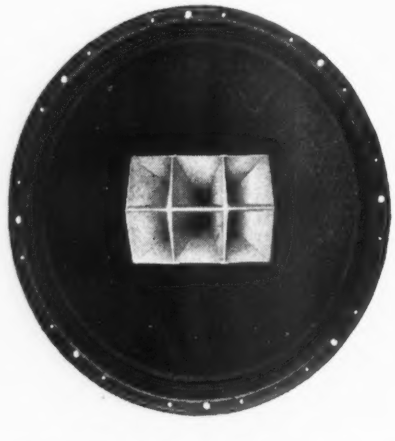
[*Continued from page 42*]

NEW MULTI-CELLULAR SPEAKER

By combining both high and low frequency units in a compact two-way multicellular loudspeaker requiring less than one and one-half cubic foot of space, Altec Lansing Corporation, Hollywood, California, has provided a point source of high quality sound for monitoring, radio, public address and recording which promises to revolutionize the field of sound reproduction. The new speaker, in actual performance, is stated to deliver up to 500% greater efficiencies in these operations. It also supplies very high quality in home radio, phonograph and f-m reproductions. Because of its high efficiency and small space requirements, it provides an ideal sound reinforcement system.

This new multi-cellular speaker provides up to 1200% increased area of distribution. In the horizontal plane, it delivers 12 times the area distribution at high frequencies as compared to the usual single unit speakers of comparable size. Its horizontal area of distribution is 60°. In the vertical plane, its area of distribution is a full 40°.

One of the most important of many factors, according to Altec Lansing engineers, is the multi-cellular high-frequency horn construction. The voice coil is wound with rectangular aluminum wire and operates in a magnetic field of very high flux density, which is supplied by a recently perfected type of permanent magnet. The aluminum alloy metal diaphragm provides mass stiffness and high velocity of transmission speed at least five times greater than through paper cone material. This high frequency unit is designed to operate as a piston up to frequencies above the limit of audibility. The high frequency



horn is a multi-cellular unit having six cells in a 2 x 3 configuration. Each cell covers a 20° solid angle, which means a combined area of distribution in the horizontal plane of 60° and 40° in the vertical plane. The high frequency horn is covered with a sound deadening material and mounted in the face of the low frequency unit. Power from the high frequency unit is supplied through the pole piece of the low frequency unit.

The three-inch voice coil of the low frequency unit is also wound with rectangular wire, and operates in a magnetic field of very high flux density, which is supplied by the newly perfected type of permanent magnet. Both the voice coil construction and the magnetic circuit design aid in delivering a very high efficiency. The low frequency voice coil assembly is mounted in a 15" stiff paper cone resonant at 38 cycles.

The input impedance of the duplex speaker is 20 ohms and a dividing network of the constant impedance type is used with a crossover frequency of 1200 cycles for separating the power for each unit. This crossover point permits the horn to adequately load the high frequency unit down to a point where litle power is being transmitted. It also eliminates any tendency to produce distortion effects as well as prevent damage to the high frequency unit. The speaker is available separately or mounted in a walnut finished cabinet. The cabinet provides eight cubic feet of air space which permits the speaker to radiate efficiently to 60 cycles for a wider range of tonal quality. Special cabinets for ceiling and sidewall mounting are available on request. A small compact 60 db gain amplifier with 15-watt output is also available for driving the speaker. Complete information may be had by writing Altec Lansing Corporation, 1210 Taft Bldg., Hollywood 28, California.

MUNGER RETURNS

Rex L. Munger, the W9LIP of amateur radio fame, has returned to his old post with Taylor Tubes, Inc., 2312 Wabansia Ave., Chicago, manufacturers of transmitting tubes, as Sales and Advertising Manager after serving for 2½ years with the Douglas Aircraft Co. in Africa and the Middle East as Technical Adviser and Representative. For a time, never far ahead of General Rommel, he had some hair-raising experiences; nevertheless, Mr. Munger took time out, whenever he could, to visit with radio distributors in South Africa, Egypt, Palestine, India, Australia, and New Zealand as he passed through these countries.

When the emergency for which he had signed up abated, Mr. Munger requested his release and headed straight back for his old chair at the firm whose name he had helped to make famous in the trade.

NEW MINIATURE TUBES

Hytron has just announced that three types have been added to its line of miniature tubes: 6AK5, 6AL5, 6AQ6.

The 6AK5 is a sharp-cutoff r.f. pentode; the 6AL5, a very-high-frequency twin diode; and the 6AQ6, a double diode triode. These Hytron tubes are now being manufactured in accordance with WPB authorized production schedules.

CORRECTION

In the Unit Conversion Table, published in the May issue, we regret that the headings for the columns "1 e.m.u. =N practical units" and 1 e.s.u.=N practical units" became transposed. If these headings are interchanged the Table will be correct.

WADSWORTH

A Tested Source for the MASS PRODUCTION of Small Precision Parts

Right now Wadsworth is making small precision parts for forty-five major companies which normally manufacture such products as radio equipment, refrigerators, automotive parts, precision instruments . . .

Typical example is a minute steel piece that receives thirty forming operations, sixteen of which are precision milling, although it weighs only 1/10th of an ounce.

After the war, manufacturers who will need small parts of this character will seek Wadsworth's small parts facilities in order to hold sales in competitive markets.

Let us discuss with you the postwar production of those small parts and sub-assemblies you may have found difficult to get in the past or may require tomorrow.

WADSWORTH FACILITIES

Die Making
Jigs & Fixtures
Gage Making
Model Building
Milling
Drilling
Turning
Stamping
Screw Machining
Hard Soldering
Heat Treating
Line Assembly
Polishing
Lacquering
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Silk Screening
Product Decorating
Metals Laboratory
Engineering Design
Product Design

CURRENTLY SERVING THESE INDUSTRIES

Aircraft
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ARMY E NAVY

SMALL PARTS DIVISION

THE *Wadsworth* WATCH CASE CO., Inc.
DAYTON, KENTUCKY, SUBURB OF CINCINNATI, OHIO
PHONE COLONIAL 8194 • (CINCINNATI EXCHANGE)
★

TECHNICANA

[*Continued from page 18*]

R2, based upon the characteristics of the British ACSP3 tube. For the 6J7 the value of *R2* would be 400,000 ohms.

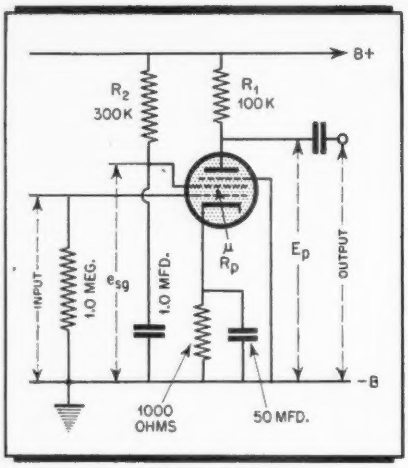

Figure 13

Second harmonic distortion tends to be unimportant with the pentode but third harmonics are present, as indicated in *Fig. 14.* With increased amplitude of input signal, the plate swing tends to flatten out at the peaks. This distortion can be reduced by keeping the plate swing low, using the lowest plate load that will give the desired output.

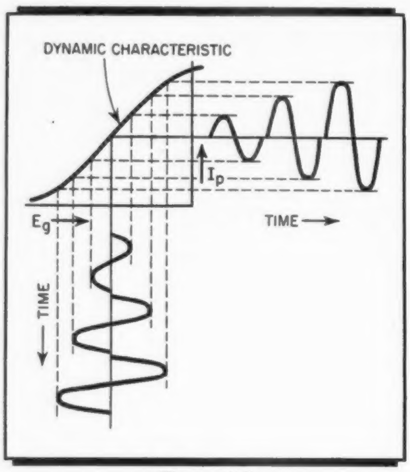

Figure 14

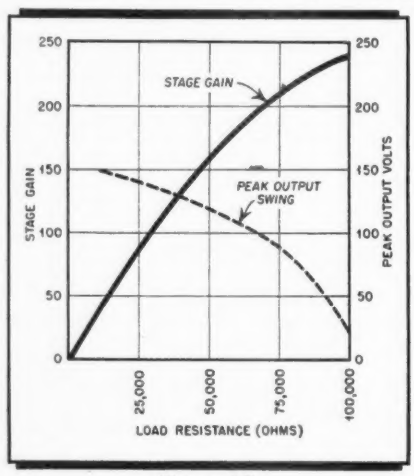

Figure 15

A high supply voltage is also desirable to increase the quiescent value of *Ep* and limit third harmonic distortion. These points are shown in *Fig. 15,* which illustrates the output obtainable for 2% third harmonic content and the stage gain change with load resistance. For every point the screen potential was adjusted to the plate potential quiescent value. Class A operation must be maintained at all times.

Even when large stage gain is not required the r-f pentode is recommended. With negative feedback distortion can be reduced to as little as 0.4% for a stage gain of 40. Voltage feedback can be obtained through two series resistances to ground, fed back at their intersection to the input. The resistance values must be carefully chosen to avoid shunting the plate load and the plate condenser selected with due regard to the lower frequency limit desired.

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L PAD

[*Continued from page 34*]

under the radical is negative, it will be necessary to substitute Z_1 for Z_2 and vice versa, as shown in *Fig. 3*, and resolve the general equation.

The equations so obtained are (8) and (9). Their use will give a positive value under the radical and allow for correct solution.

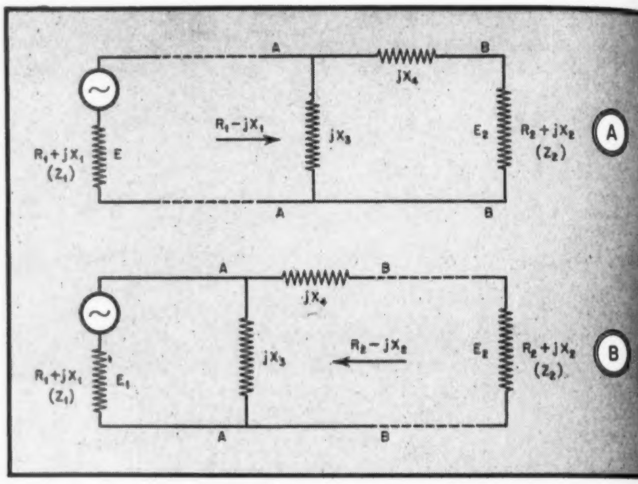


Fig. 2. Generator with conjugate load, (A), and, (B), load with conjugate impedance

$$X_3 = \frac{R_1X_2+\sqrt{R_1R_2X_2^2+R_2^3R_1-R_1^2R_2^2}}{R_2-R_1} \quad \ldots (8A)$$

$$X_4 = -\frac{R_2X_1+\sqrt{R_1R_2X_2^2+R_2^3R_1-R_1^2R_2^2}}{R_2} \quad \ldots (8B)$$

$$X_3 = \frac{R_1X_2-\sqrt{R_1R_2X_2^2+R_2^3R_1-R_1^2R_2^2}}{R_2-R_1} \quad \ldots (9A)$$

$$X_4 = -\frac{R_2X_1-\sqrt{R_1R_2X_2^2+R_2^3R_1-R_1^2R_2^2}}{R_2} \quad \ldots (9B)$$

In certain cases it is found that even though Z_1 and Z_2 are reversed in the circuit the expression under the radical is always positive, allowing use of equations (6), (7), (8), and (9).

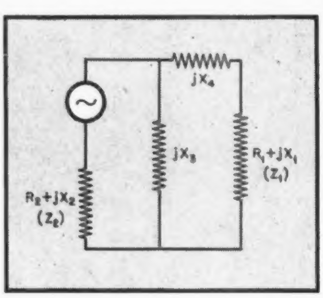
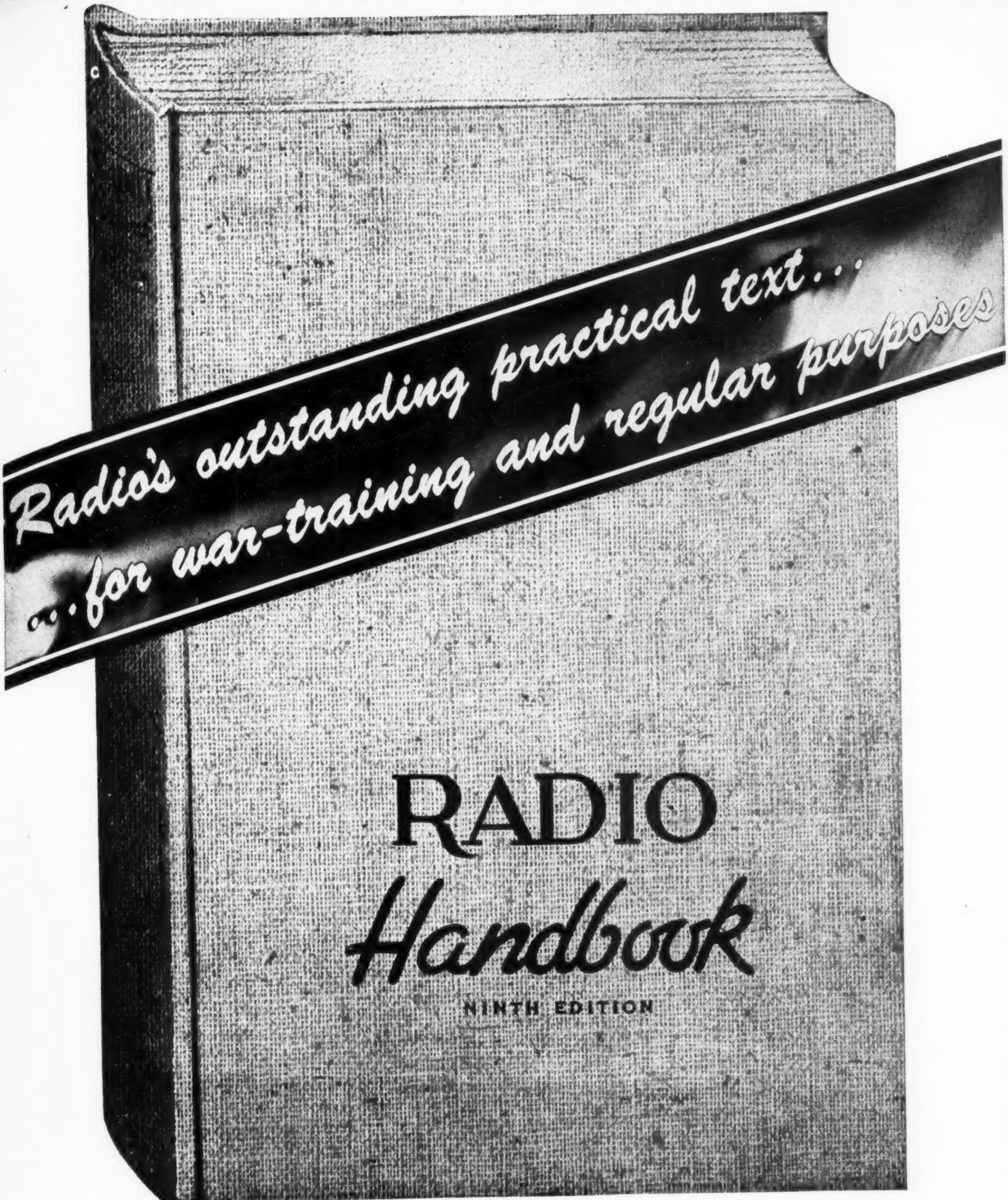


Fig. 3. Equivalent circuit used when expression under radical is negative

This gives a total of four different values for the L pad that satisfy the conditions of maximum power transfer.

It will usually be desirable to equate for all possible solutions, as circuit design may often dictate one type of network over another, in regard to the desirability of d-c coupling, or of the effect of the network on other frequencies that may be present. The phase angle between input and output can readily be obtained by drawing the vector diagram of the circuit, and computing the angle between E_1 and E_2.

[*Continued on page 66*]



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RESISTORS

[*Continued from page 33*]

a.) Ayrton-Perry
b.) Bifilar
c.) Pie
d.) Modified Pie
e.) Straight Wire

The Ayrton-Perry method consists of two windings, connected in parallel, and wound in opposite directions. Assuming 100% coupling and uniform distributed inductance on each winding, the net inductance is zero. This type of winding is used in the vitreous, organic, and axial types previously discussed. The result with careful winding is an inductance in the neighborhood of several microhenries or less with a resistance value of 1000 ohms.

In bifilar windings, two wires (or a single wire folded back on itself) are wound in parallel on the same form. Two ends are joined to form a U-shaped conductor, the two remaining ends being the terminals. Thus close coupling is secured throughout the winding. In practice, this winding is not as non-inductive as the first method, but it is useful where small resistances are desired and where small size is a requirement. The voltage gradient is high because the potential difference between the two adjacent wires comprising the bifilar winding increases as the ends are approached.

The pie method consists of a single wire wound in one direction in one pie (or segment) of the spool and in the opposite direction on the succeeding pie, etc. It is often assumed that there is 100% coupling between the sections, that the number of turns is uniform on each pie and that the pies are wound in the same fashion. This is not true in practice, for the spool segments are usually wound non-uniformly and with heavy lava or steatite barriers the coupling is rarely above 10% to 20%. Units of 1000-ohm resistance value have an inductance of 1 to 10 millihenries.

The modified pie method is employed where each layer of wire is insulated by a layer of paper. Here the direction of winding is frequently reversed to balance out the inductance. The failures noted above under the pie method hold here.

The straight wire method is a process for embedding a straight length of resistance wire in a mica form. Here the inductance is, obviously, reduced to the inductance of a straight wire. This method leads to a limitation of maximum resistance obtainable.

It should be pointed out, however, that the effects of inductance and capacitance need not usually be taken into consideration until the audio range is passed. Beyond this point distributed capacitance and inductance cause the effective resistance to vary unpredictably.

Such a statement as this must be general for measurements on resistors supplied by the same manufacturer of the same lot varied from resistor to resistor with noticeable and different resonant peaks in the low megacycle region, and with a serious decrease of effective resistance at the frequency increased above the point of resonance.

There are many fields yet to conquer in resistor construction: improvement of the high frequency characteristics of resistors, improvement of the stability of composition types, improvement of wire insulation or winding techniques to permit a large range of resistance on wire-wound units.

L PAD

[*Continued from page 64*]

Numerical Values

Numerical values can be substituted in equations (6) to (9) inclusive, the j operator not being used, using the conventional "minus" sign for capacitive reactance and "plus" sign for inductive reactance. The sign of the answer will tell whether the reactance solved for is inductive or capacitive.

Where the impedances Z_1 and Z_2 are both resistive, the equations simplify to equations (10) and (11), and the phase angle between input and output voltage is

$$\cos^{-1} = \frac{\sqrt{R_1 R_2}}{R_1}$$

the phase being retarded when X_3 is negative, and advanced when X_3 is positive. When Z_1 and Z_2 (*Fig. 2A*) are both resistive, Z_1 is always made the higher value to insure positive values under the radical in equations (10) and (11).

$$X_3 = + R_1 \sqrt{\frac{R_2}{R_1 - R_2}} \quad \ldots\ldots\ldots (10A)$$

$$X_4 = - \sqrt{R_2(R_1 - R_2)} \quad \ldots\ldots\ldots (10B)$$

$$X_3 = - R_1 \sqrt{\frac{R_2}{R_1 - R_2}} \quad \ldots\ldots\ldots (11A)$$

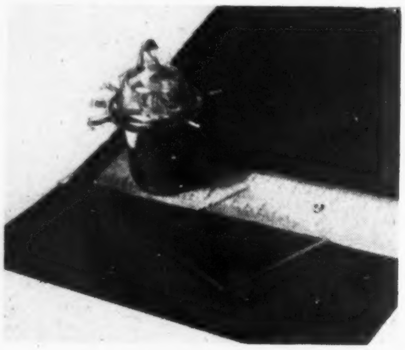
$$X_4 = + \sqrt{R_2(R_1 - R_2)} \quad \ldots\ldots\ldots (11B)$$

CRYSTAL CIRCUITS

[*Continued from page 29*]

The grid and plate capacities are then tuned to the crystal frequency and the oscillator will then oscillate and be controlled by the crystal only.

The temperature coefficient characteristics of crystals operated at their high harmonics have drift percentages directly related to the rate of change for frequency with temperature of the fundamental frequency of the crystal. For example, at ten megacycles, if a drift of two cycles per megacycle for a



Size of quartz crystal plate in comparison with typical acorn tube

single degree centigrade is assumed, a total drift of twenty cycles would be obtained. If, at the fifth harmonic or fifty megacycles, a measurement under the same conditions was made a total drift of one hundred cycles would result.

Frequency stabilities much better than the above mentioned are very possible as well as r-f output somewhat above one hundred megacycles, from the oscillator stage alone. Tubes such as the 952 acorn pentode may be used in the circuit of *Fig. 7*, or other beam power tubes capable of more output and comparing favorably in electrical efficiency at these frequencies.

* Patent No. 2,259,528.

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